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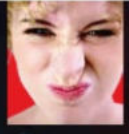

WHAT MAKES US DISGUSTED?
The intriguing science behind moral judgements

FOCUS
SCIENCE AND TECHNOLOGY

Stephen Hawking
New film: the verdict

ET on Earth?
Evidence could be encoded in our genes

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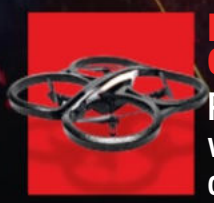
THE UNIVERSE
THE STORY SO FAR

What the latest discoveries tell us about the Big Bang, dark matter and multiple universes

PLUS HOW TO SURVIVE A DISASTER IN SPACE

PLAYING GOD WITH BIOLOGY
The revolution behind glowing trees and DNA computers

Q&A
- Which drink is better for you – cola or diet cola?
- Why do we have eyebrows?
- Do carrots help you see in the dark?



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WELCOME TO FOCUS

JUST 50 YEARS ago, the Universe was pretty much a mystery. Scientists couldn't agree on whether it had always existed, or whether it exploded into life in a 'Big Bang'. Today, the debate has been settled. And thanks to measurements made this year by a spacecraft called Planck, we know to a pretty high precision exactly when the Big Bang happened. But as we've discovered more, mysteries like dark matter, dark energy and multiple universes have reared their ugly heads. So in this issue we've rounded up everything you need to know about the Universe. Let Stuart Clark be your cosmic tour guide on p36.

Back down on Earth, biologists in California have genetically modified a plant to glow in the dark. Ultimately, they hope that glowing foliage could replace living room lamps and even streetlights. The plant is just one project in the exciting new field of synthetic biology. Turn to p53 for more mind-blowing examples of genetic manipulation from Adam Rutherford, the presenter of BBC Radio 4's *Inside Science*.

I'm sure not everyone approves of synthetic biology. In fact, some may even be disgusted by it. But what exactly is disgust, and why are we disgusted by things others find acceptable? Surprisingly, the answer may have more than a little to do with evolution, as anthropologist Val Curtis explains on p61.

There's plenty more in this issue, including my review of the new film *Hawking* on p95. Until next issue,

Graham Southorn, Editor

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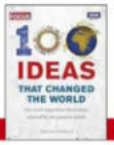

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APPEARING IN THIS ISSUE...

Stuart Clark
With a PhD in astrophysics, Stuart is one of the UK's most widely-read astronomy journalists. On p36 he looks at how new discoveries are rewriting the most epic story ever told – the history of our Universe.

Valerie Curtis
Maggots, mould and mucus might make you gag, but for the director of the Hygiene Centre at the London school of Hygiene and Tropical Medicine, they're fairly mundane. On p61, Dr Valerie Curtis looks at the science of being disgusted.

Kelly Oakes
Science writer Kelly is a regular contributor to *BBC Focus Magazine*. With the film *Gravity* starring Sandra Bullock and George Clooney soon to hit cinemas, she looks at what happens when things go badly wrong in space on p48.

Adam Rutherford
As the presenter of Radio 4's daily science show *Inside Science*, Dr Adam Rutherford's voice is never far from the cutting-edge of science. He counts down the most exciting breakthroughs in the field of synthetic biology on p53.

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COVER: MAGICTORCH

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BE AN INSIDER

We want to know what you think – the more we know about you, the better placed we are to bring you the best magazine possible. So we'd like to invite you to join our online reader panel, 'Insiders'.

Interested? Log on to **www.immediateinsiders.com/register** to fill out the short registration survey and we'll be in touch from time to time to ask for your opinions on the magazine and other relevant issues.

We look forward to hearing from you soon!

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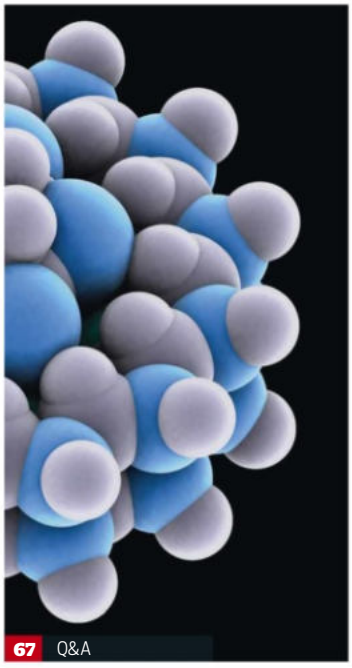
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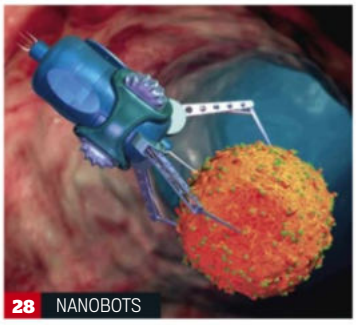
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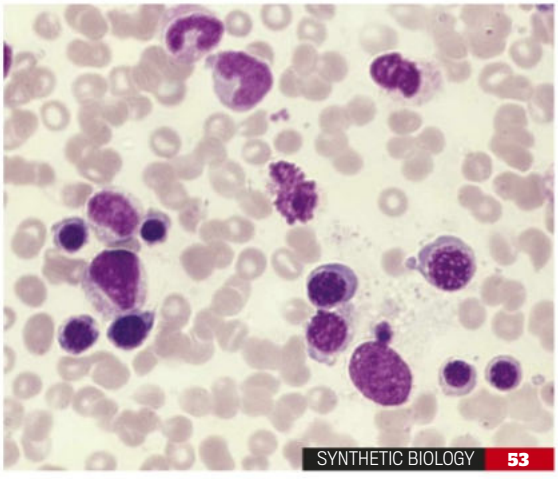

SYNTHETIC BIOLOGY 53

Awe-inspiring images from the world of science

MegaPixel

Living larder

ALTHOUGH THEY'RE TRYING their best to look like a bunch of grapes, this is actually a group of honeypot ants hanging upside down. They have gorged on nectar during wet weather, storing it in their abdomens to provide food for the colony.

"When other workers are hungry and they aren't able to find food in the normal way, they will just come along and stroke the antennae of these hanging workers, who will then regurgitate the food," says Dr George McGavin, author, BBC TV presenter and honorary research associate in the University of Oxford's zoology department.

There are several species of honeypot ant, but these belong to the species *Camponotus inflatus* and were photographed in central Australia. They often become so large that they are unable to move. They are precious when food is in short supply and can be stolen by other ant colonies. "I've eaten lots of insects, but this is one I haven't tried," says McGavin. "They are delicious apparently. In Australia they are a real treat for Aboriginals."

PHOTO: FLPA

For more great pictures, follow us on
http://pinterest.com/sciencefocus

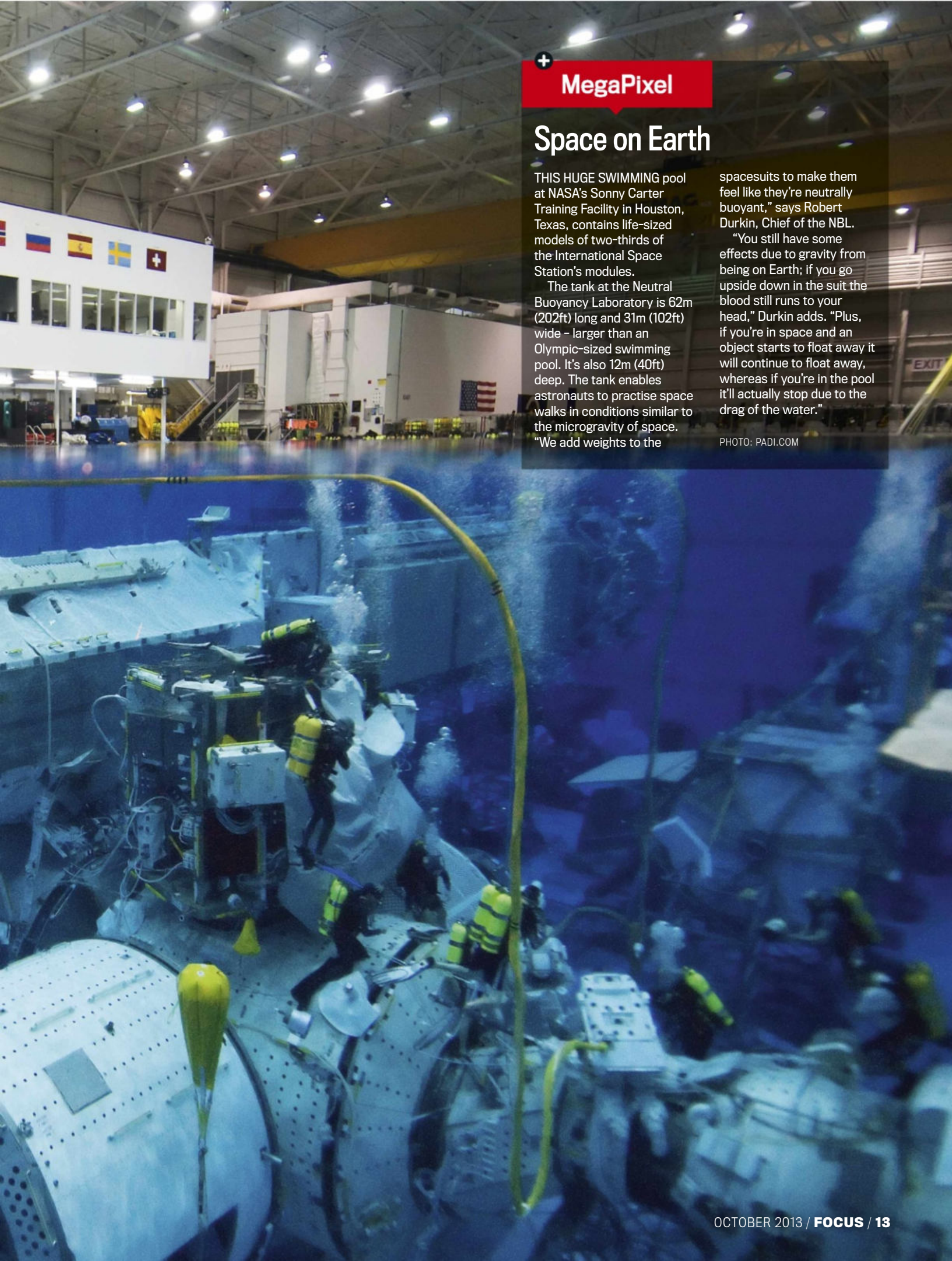
MegaPixel

Escaping the grave

THIS IS WHAT remains of what was once a lively town. Tourists visiting Villa Epecuén in Argentina would head for Lake Epecuén to bathe in the salty waters, hoping it would cure their ills.

But the lake that enabled this resort to grow engulfed it in 1985 when it flooded. "The period since the 1970s was exceptionally wet, and so the resort, established in the 1920s, became flooded in spite of the building of a dam to try and protect it," says Professor Andrew Goudie, Emeritus Professor of Geography at the University of Oxford. "Now the climate has reverted to what it was like in the earlier 20th Century and so the lake has started to dry out, exposing the formerly flooded resort."

PHOTO: GETTY



MegaPixel

Space on Earth

THIS HUGE SWIMMING pool at NASA's Sonny Carter Training Facility in Houston, Texas, contains life-sized models of two-thirds of the International Space Station's modules.

The tank at the Neutral Buoyancy Laboratory is 62m (202ft) long and 31m (102ft) wide – larger than an Olympic-sized swimming pool. It's also 12m (40ft) deep. The tank enables astronauts to practise space walks in conditions similar to the microgravity of space. "We add weights to the spacesuits to make them feel like they're neutrally buoyant," says Robert Durkin, Chief of the NBL.

"You still have some effects due to gravity from being on Earth; if you go upside down in the suit the blood still runs to your head," Durkin adds. "Plus, if you're in space and an object starts to float away it will continue to float away, whereas if you're in the pool it'll actually stop due to the drag of the water."

PHOTO: PADI.COM

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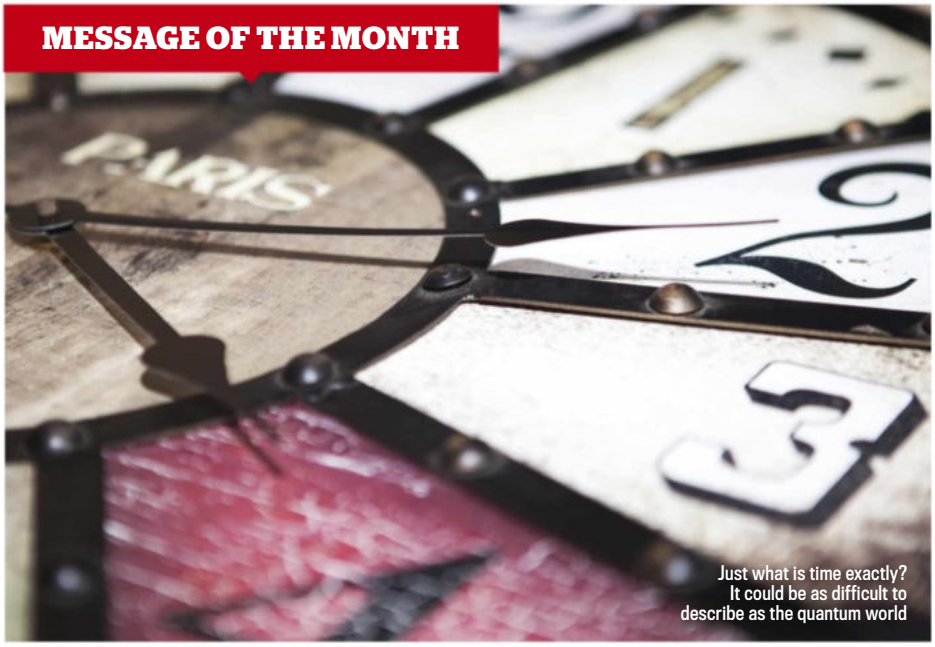
MESSAGE OF THE MONTH



Just what is time exactly? It could be as difficult to describe as the quantum world

Time for a new meaning?

Robert Matthews has set an intriguing hare running in his article on 'time'. I am in awe of the power of mathematics to describe the workings of the Universe, but in this particular case I wonder whether its authority might obscure just what time is. As I read the article I was reminded of the problem that the early pioneers of quantum theory faced. They were grappling with such non-intuitive ideas that they found it hard to describe them. In consequence they fell back on using everyday language that was really not appropriate. After all, how can something be described as both a wave and a particle?

Maybe the same thing is happening here. We have an everyday meaning for the word 'time', the passage of events. The word 'passage' implies movement, and movement has a rate attached to it. Paul Davies's reply, when asked how fast time goes, was "one second per second". This expression has no dimensions, as the units of second in the numerator will cancel out the units of second in the denominator. Does this imply that time does not exist?

Perhaps the solution to the conundrum that faces Lee Smolin and Bryce DeWitt is to look at time as both existing and not existing, and use words that do not relate to our everyday concept. With this baggage out of the way, mathematics can reassert itself and, as with quantum theory, start to lead to a real understanding of our existence.

Alan Hudson

Write in and win!

The writer of next issue's Message of the Month wins a pair of VOX amPhones, worth £119. AmPhones recreate the sound of classic VOX amps used by The Beatles and The Rolling Stones. AmPhones are available in four different versions, all with a different sound. Visit www.voxamps.com

True grit

The question of my fellow townie Simon Vincent (Q&A, July 2013), 'Can chewing gum help you concentrate?' may have another component to one already offered in your answer: 'It may be that the tongue and jaw manipulation involved in moving gum around your mouth occupies parts of the brain that might otherwise get distracted.' This would seem crucial, as experience teaches us that when the body is occupied by some, usually repetitive, action the mind tends to be freed and made clear to concentrate and more conducive to insight.

Maybe there is something also in the act of 'gritting the teeth', which tends to up our game and increase determination and hence concentration when effort is required. I find this when working out. When the going gets tough and the pressure is on, I tend naturally to 'grit my teeth', which the action of chewing gum may partly replicate. This action tends to give an edge of aggression, which focuses attention. People say this when we're required to prepare for an unpleasant situation that requires us to focus and steel ourselves: "Grit your teeth!"

Peter Davis, King's Lynn, Norfolk

Measuring pain

In your August Message of the Month, written by Dr Macnair, she wrote about the subjective nature of pain and the impossibility of a scan to 'measure' pain. While I respect and agree with her desire to view patients holistically, I do believe that we will be able to quantify pain in the near future.

Pain is detected by neurones in the brain. Regardless of the individual's situation or history, pain is perceived by the brain in the activation of select neurones. This is physiology. If we can assess the extent of activation of these neurones, it stands to reason that this can be correlated to the amount of pain being experienced by the sufferer. I think that this is an exciting development and will have many applications in medicine.

Dr Alexander Van Heerden, South Africa

PHOTO: GETTY

Arguments for extinction

Reading the article 'Leap in cloning could resurrect bizarre frog' (June, p19) really got me thinking. As I understand it, natural selection is a process by which living organisms that cannot adapt to their changing environment are removed from existence so that their 'disadvantageous' genes are not passed on to future generations. I am not saying that all creatures on the endangered species list should be ignored, but it does beg the question, are all endangered species worth saving?

We as humans are changing the planet in ways that we still don't fully understand. What we do know is that we are changing many animals' environments, but how do we determine which ones are going extinct due to our actions or from their own natural selection processes? To eventually save all endangered species would be to go against millions of years of evolution, thus halting it in its footsteps. This would have far more dire consequences than allowing certain species to become extinct.

As mentioned in the article, 'we urgently need gene banks for the animals that are vanishing'. I would agree for animals whose environments are obviously being affected by humans, such as the Chinese Giant Salamander and the Siberian Tiger, but all animals? To do so would be to act as Gods. Are we not, after all, creatures of natural selection, so theoretically we shouldn't have any issue causing other animals' extinctions. We are simply out-competing everything else.
Charlie Barty-King

Poaching has nearly wiped out the Siberian tiger

PHOTO: THINKSTOCK

The case against biofuels

I have never understood the logic for most biofuel research. Surely food production must take priority? Using biological waste, or a crop like Jatropha (an oil producing crop that can grow in arid regions where normal food crops cannot) makes sense. However, most biofuel crops seem to be grown on perfectly good farmland.

If you want to use land to provide energy then solar panels must provide a more efficient conversion of the Sun's energy. A potentially more fruitful line of research would be to develop transparent solar panels that only make use of the green part of the spectrum. They wouldn't be particularly efficient because they'd only use a fraction of the available light but could have a potentially huge 'catchment' area as a 'roof' over crops, which should grow perfectly well underneath because they don't need the green light the panels absorb.
Geoff Dunwell, Maidenhead

Sentient probes

Re: Stephen Baxter's sentient probes (August, p122), Greg Bear has an excellent novel, *Queen Of Angels*, concerning the ethics of sending sentient (AI) probes into the big black nothing. For examples of what happens to intelligence lost in space with no-one to talk to, see Earth.
Luke Daniel

How would an AI robot cope with the isolation of space?

Oops!

• The credit for materials used in last issue's feature 'The Resurrection Of Egypt's Lost City' should have read 'Photos: Christoph Gerigk/ Franck Goddio/Hilti Foundation; Graphic: Yann Bernard/Franck Goddio/Hilti Foundation'.

YOUR COMMENTS ON OUR FORUM

Shadowwolf Can science explain pessimism? As Churchill indicated, the pessimist sees the difficulty. However, this ensures that issues are corrected prior to trying.

M Paul Lloyd I half watched something about this on the TV last night, and I can't say that I was all that convinced.

Lateralman If you had watched the other half you would have been more optimistic.

Join in the discussion at www.sciencefocus.com/forum

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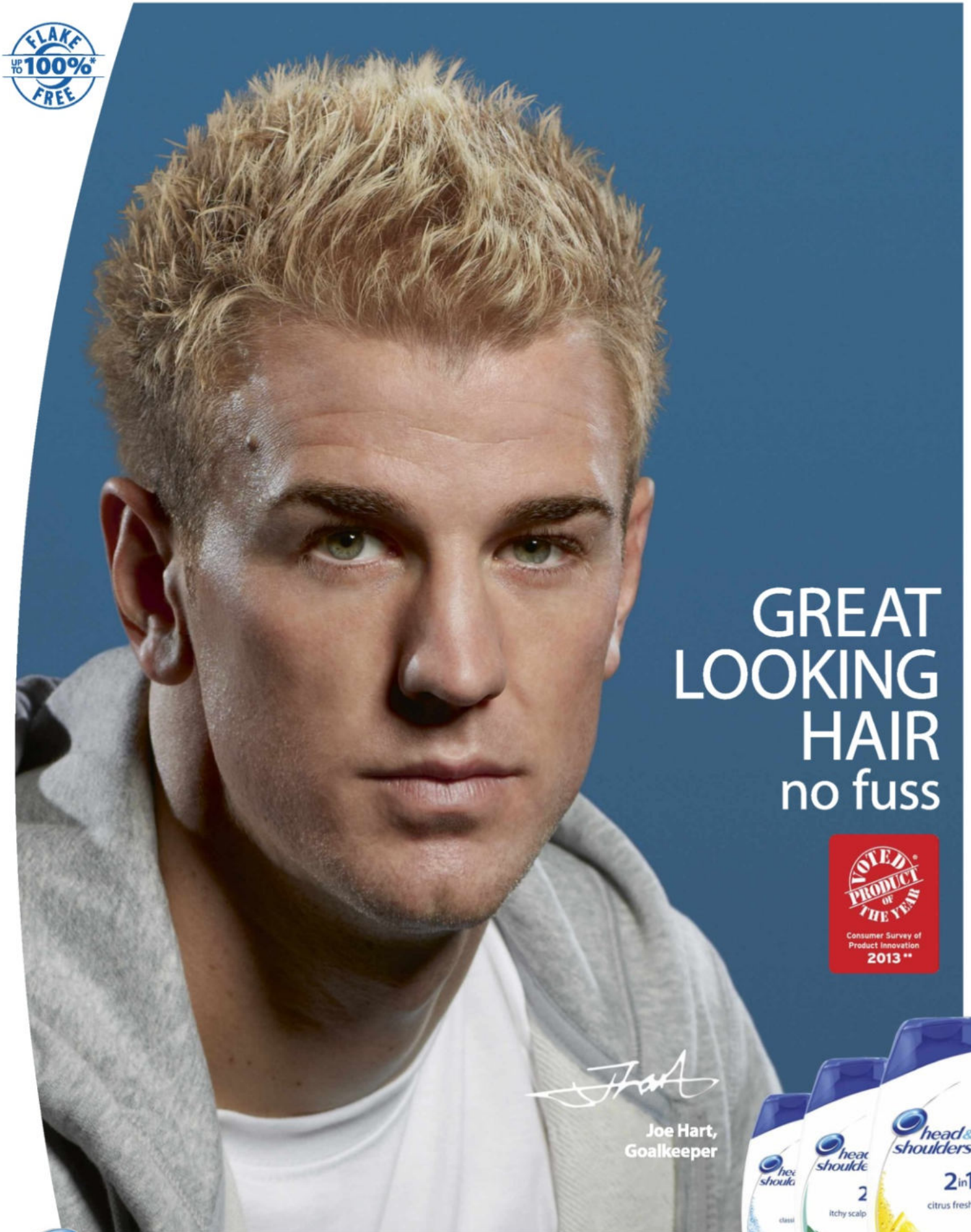

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The Chelyabinsk meteor could have an army of siblings heading our way

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WANT FRIES WITH THAT?
We asked: would you eat a burger that was grown in a lab? Here's what you told us...

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BIONIC BEES TAKE OFF
Tiny flying robots could be the future of search and rescue operations

THE BIG STORY

Genes shape how we smell the world

DNA-determined differences in odour sensitivity will lead to personalised perfumes and food

WE'VE KNOWN FOR some time that our ability to detect different smells varies from person to person. Now, new research shows how big an influence our genetic make-up has on our sense of smell. It means we can expect a future of personalised fragrances and food, where perfumes and meals are optimised for our individual mix of genes.

Researchers in New Zealand tested nearly 200 people's sensitivity to different smelling chemicals before sequencing the volunteers' genomes. They then looked

More evidence has emerged of the link between our genes and our sensitivity to odours

PHOTO: GETTY

The New Zealand Institute for Plant and Food Research has been researching people's sensitivity to odours

for associations between genes and smell sensitivity. With four of the odours, groups of genes were found that were responsible for differences in smell sensitivity. The links between genes and sensitivity were not so clear with the other odours.

While genetic differences in odour sensitivity have been found before, this new research almost doubles the number of regions in the human genetic code that are believed to be linked with smell sensitivity.

There was nothing particularly unusual about the odours which we now know we smell to a different extent depending on our genes. It's not unreasonable to assume that other odour sensitivities would also be under genetic control.

"If we extrapolate across many compounds, we probably all live in our own unique flavour world," says Associate Professor Richard Newcomb, an evolutionary geneticist at the University of Auckland, who led the research.

Newcomb's team went on to find that, in the case of one of the smelly compounds – beta-ionine, the chemical that gives violets their distinctive fragrance – the difference between less sensitive and more sensitive smellers was caused by one small genetic change inside an odorant receptor. Newcomb says that this change leads to the swapping of a small component of a protein with another one. "It turned out to be a single amino acid substitution – the simplest genetic change possible," he says.

The other genetic associations were found in the sensitivity to the chemicals that give blue cheese, malt and apples their odours.

Our sense of smell contributes to our perception of flavour, so these differences in odour perception will have an influence on the taste we each attribute to different foodstuffs. Newcomb suggests that in the future, smells of perfumes and household products, and the flavours of foods and drinks could be personalised.

"We would like to see how we could help food companies develop better products with this information," says Newcomb. "For beta-ionine, for example, a product developer might want to make sure they have products that are able to target both the good and the less sensitive smellers."

PENNY SARCHET

ANALYSIS
Joel Mainland

Professor of Ultrasonics at the University of Bristol

"WE KNOW THAT receptors are the key to sensing odours, but we don't understand how blocking or activating one receptor will alter perception. Will it change the intensity of an odour? Will it shift the odour from floral to faecal? By examining natural genetic variation, these findings begin to address this question.

We already knew that humans have significant variation in olfactory perception, but it was unclear how much of that was due to culture and learning, and how much was due to genes. Prior to these results, there had been five examples where variation in sensing smell had been traced to a region of the genome.

This new work makes the important point that genetic variation in receptors can have a profound effect on what kinds of food we like. It explores the mechanisms of odour perception, and shows how genetic variation can really change how people respond to these different flavours and fragrances.

The obvious application of this research is in the flavour and fragrance industry. Understanding an individual's genetics could help you understand their preferences. More broadly, understanding the distribution of certain receptors in different ethnic groups may also help uncover why certain cultures like specific foods, and might help us understand the evolution of dietary preferences."

WHAT DO YOU THINK?

Would you like to see foodstuffs tailored to your genes? Let us know your thoughts at facebook.com/sciencefocus

TIMELINE
How the genetic link to odour sensitivity emerged

1918
American botanist Albert Francis Blakeslee reports that humans differ in their sensitivity to the scents of some flowers, finding that some are 'blind' to the smell of some verbenas.

1931
In a lab mishap, scientists discover that some people are unable to sense the bitter-tasting chemical phenylthiocarbamide. This difference is found to be under genetic control.

1986
The genes for the eye pigments humans use to detect colour are identified. Red-green colour blindness is found to be linked to changes in the red and green pigment genes.

2006
A genetic difference in a human taste-receptor is found to affect how plants like broccoli, which contain phenylthiocarbamide-like chemicals, taste to different individuals.

2007
The chemical androstenone smells like flowers to some people and like urine to others. It's the first difference in smell traced to genetic differences in an odorant receptor.

2013
A research team in New Zealand finds groups of genes that determine our sensitivity to four odours, almost doubling the known genetic associations with smell sensitivity.

PHOTO: THE NEW ZEALAND INSTITUTE FOR PLANT AND FOOD RESEARCH. FREMONT DAVIS, PRESS ASSOCIATION. ELONMUSK.COM

The Chelyabinsk meteor appeared as a fireball in the Russian sky. Inset: Fragments of the space rock

Astronomy

Siberian space rock's neighbours may head our way

THE DAYLIGHT FIREBALL that exploded like a second sun over the Siberian city of Chelyabinsk earlier this year may be part of a family that threatens more impacts in future.

The 18m-wide, 11,000-tonne space rock appeared without warning on 15 February. It deposited a shower of meteorites around Lake Chebarkul following a sonic boom that shattered windows, damaged buildings and injured more than 1,000 people.

From its track through the atmosphere, filmed by several cameras, estimates of the impactor's orbit have been made. From that data, two scientist brothers have run billions of computer simulations to help them identify around 20 asteroids on similar tracks.

Professors Carlos and Raúl de la Fuente Marcos, who study orbital dynamics at the Complutense University of Madrid, say the most likely source of the space rock that hit Chelyabinsk is a 200-metre wide asteroid labelled 2011 EO_{40}. They suggest 2011 EO_{40} and February's impactor may both be fragments of a larger asteroid that broke up between 20,000 and 40,000 years ago.

"If indeed the Chelyabinsk superbolide was a fragment of 2011 EO_{40}, or any other asteroid for that matter, it is very likely that many other fragments were produced during the break-up event," says Carlos.

The existence of sibling chunks suggests that similar impacts with Earth could occur in the future. However, the brothers admit that more work and observations are needed to refine the orbits of 2011 EO_{40} and other possible relatives.

More proof that 2011 EO_{40} was the source of the superbolide would come if samples from the two objects matched. "Unfortunately, a sample-return mission would cost a fortune and require several years of planning," says Carlos. "But a quicker, and cheap, alternative would be spectroscopy."

"A large ground-based telescope or the Hubble Space Telescope may be able to obtain the spectrum of 2011 EO_{40} when it becomes bright enough in June next year. If the composition deduced from the spectrum matches the one found for the meteorites, a genetic relationship can be claimed."

PAUL SUTHERLAND

1 MINUTE EXPERT

E-skin

What's that?
It's a flexible, paper-thin material that lights up when touched. Just like real skin, it senses pressure: the harder it's pressed, the brighter it shines.

How was it made?
Researchers at the University of California, Berkeley coated a silicon wafer with a thin layer of plastic. Once the plastic had hardened, the skin's electronic components were stacked on top. The silicon base was then peeled away, leaving a bendy film embedded with sensors.

How does it work?
The e-skin's surface consists of a grid of pixels each housing a transistor, an organic light-emitting diode (OLED) and a rubber sensor embedded with conductive carbon nanoparticles. Pressing a sensor brings the nanoparticles closer together, increasing the current and brightening the OLED. Only the pixels being pressed light up.

What could it be used for?
The e-skin could provide robots with a finer sense of touch, or be used to create an interactive wallpaper. Extra sensors could also be incorporated into the e-skin so that it can detect things other than pressure. For example, it might be wrapped around a patient's arm to monitor their temperature and pulse rate.

WHO'S IN THE NEWS?

Elon Musk

Billionaire founder of SpaceX and co-founder of Tesla Motors and PayPal

What did he say?
He proposed a 'Hyperloop' that would carry passengers between Los Angeles and San Francisco in aluminium pods at up to 1,220km/h (760mph). In a document outlining his idea (http://bit.ly/17JKhpq) he says: "Short of figuring out real teleportation... the only option for superfast travel is to build a tube over or under the ground that contains a special environment."

What's so special about the environment?
Each pod would be suspended on a cushion of air and be propelled through the low-pressure tubes by magnets and fans. Capsules would travel between the cities in a loop, departing every 30 seconds.

When will it be built?
That's far from clear. Musk says he's too busy working on SpaceX and Tesla to build the network himself, and is hoping others will take up the challenge. There's also the small matter of cost: an estimated $6bn for a system with people-only pods, or $10bn for pods carrying cars as well as passengers.

PATENTLY OBVIOUS

Inventions and discoveries that will change the world with James Lloyd

Photos get more personal

THE LAST FEW years have seen an explosion in the number of personal health- and fitness-monitoring gadgets. Now, though, Sony is looking to take things further by tagging photos with your vital signs.

Sony's system will use hidden sensors in your smartphone to record your biological data as you take a photo. These sensors, which could be concealed in the camera button or inside the device's casing, could measure your body temperature, pulse rate, blood pressure and blood oxygen level.

Once the system has tagged the photo with your bodily statistics, you'll be able to sort your snaps by the state you were in when you took them. This means you'll be able to create an album of those pulse-racing close encounters while on safari in Africa... or just track your stress levels over the course of a family Christmas. The technology might also let you take a 'selfie' embedded with your vital signs that you could then send to your GP for analysis.

Patent application number: US 20130182144

Touchy-feely gadgets

WE'RE ACCUSTOMED TO having touchscreens on our gadgets, but now Microsoft is looking to cover its entire devices with a sensitive skin that'll respond to your every whim. Microsoft's patent application describes how its touch-aware skin will be embedded with a grid of sensors.

These will detect how you're gripping the device, automatically shifting the position of menus, windows, and other on-screen interfaces to match your grip pattern, beyond simply swapping between landscape and portrait orientation as on current devices. Some of the sensors may also incorporate fingerprint recognition to instantly unlock the device as you pick it up. Touch-sensitivity on the back of the device will let you navigate websites, control media players and flick through eBooks without obscuring the screen.

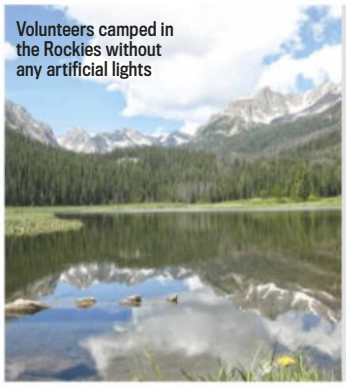
Two devices sporting this technology could even interact with each other – bumping them edge-to-edge, for example, might transfer photos between them.

Patent application number: US 20130181902

The stray ski finder

Darren Grix in Kent has invented a device called FindSki to help retrieve skis that have been lost in deep powder snow. You wear a pouch on your leg containing a brightly-coloured beacon in the form of a nylon disk. When a ski comes off, it pulls on a cord attached to the beacon, popping it out of the pouch. The cord then retracts, pulling the beacon towards the ski so that you can easily locate it.

Patent application number: GB 2498985



Volunteers camped in the Rockies without any artificial lights

PHOTO: KENNETH WRIGHT ILLUSTRATOR: ROBIN BOYDEN

THEY DID WHAT?!

Volunteers abandon artificial light

Eight volunteers spent a week camping without any sources of artificial light, including torches, wearing watches with sensors that monitored light levels and their sleeping habits.

Why did they do this?
Scientists wanted to find out how artificial light affects our sleeping patterns. Before the trip, the volunteers had their normal sleeping patterns monitored.

So what happened?
The campers' sleep cycles became more synchronised with the rising and setting of the Sun. On average, they fell asleep and woke up two hours earlier than usual, with those who were 'night owls' experiencing the most dramatic shifts. The researchers at the University of Colorado Boulder say that increasing our exposure to natural light can reset our body clocks, helping us to feel more lively in the morning.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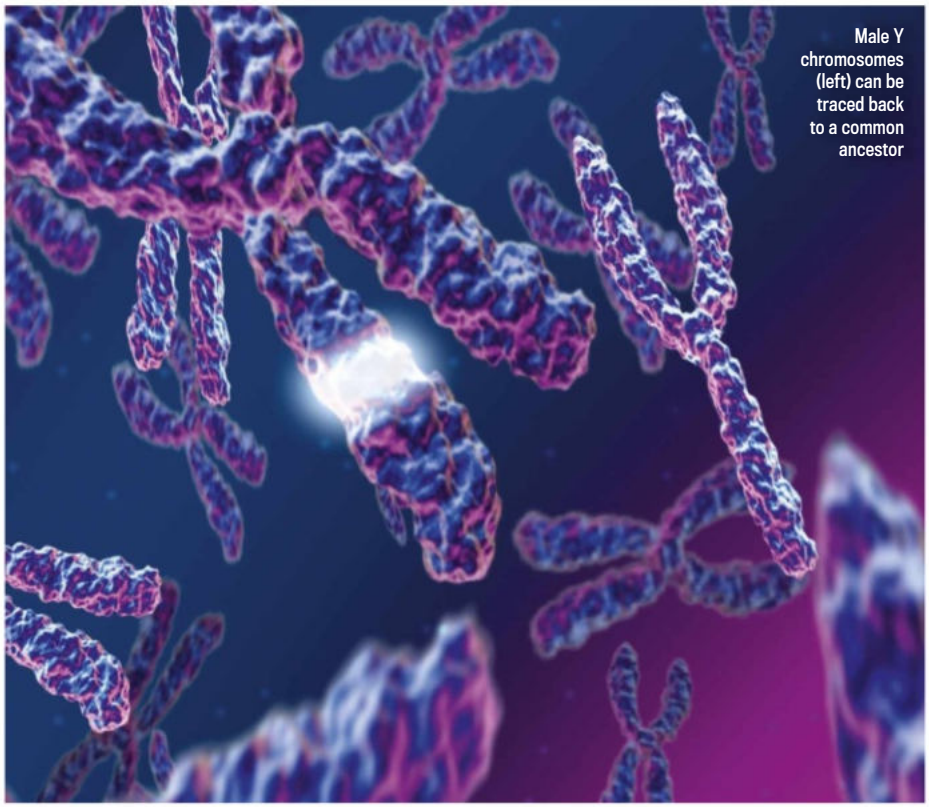
Genetics

Genetic Adam and Eve lived around the same time



Male Y chromosomes (left) can be traced back to a common ancestor

ALMOST ALL MEN alive today can trace their male Y chromosome back to a common ancestor who walked the Earth around 140,000 years ago, a new study reveals. 'Y-chromosomal Adam', as he's known, likely walked the planet at the same time as 'Mitochondrial Eve,' the most recent common ancestor of modern women.

Previous estimates of when the genetic 'Adam and Eve' lived have suggested that they were around at different times – around 100,000 and 200,000 years ago respectively. But new research at Stanford University suggests that Y-chromosomal Adam lived earlier, between 120,000 and 156,000 years ago – roughly the same time as Mitochondrial Eve, who lived between 99,000 and 148,000 years ago.

Although the new calculations indicate that they may have been contemporaries in Africa, it's unlikely this genetic Adam and Eve ever met. There were tens of thousands of humans around at the time. "It's just that one man had the good fortune to have his Y chromosome survive to this day," says David Poznik, co-author of the research. One woman's mitochondrial DNA survives to this day, too.

The team arrived at their estimates by sequencing the parts of the genome that are passed from generation to generation without mixing – part of the Y chromosome, and also mitochondrial DNA, which is passed from mother to son and daughter and so provides a route to trace the maternal lineage.

By comparing these regions from 69 geographically diverse men, the team identified thousands of tiny genetic sequence variations, hewn by random mutation over the millennia. Knowing this, and also the rate at which mutations arise in a population over time, they were able to calculate when our common male and female ancestors would have lived.

HELEN PILCHER

PHOTO: SCIENCE PHOTO LIBRARY, PRESS ASSOCIATION

HOT TOPIC

Would you eat a lab-grown burger?

The £215,000 burger

IT TOOK three months and £215,000 to make, and the first lab-grown burger got a largely positive response at a recent tasting event in London.

The burger, grown by Professor Mark Post at Maastricht University in the Netherlands, started off as stem cells extracted from cow muscle tissue. Their job is usually to repair damaged tissue by turning into new muscle cells. These cells were cultured with nutrients to help them develop and multiply. They were then turned into muscle cells by stretching them, and subsequently compacted into a patty. A dash of beetroot juice and saffron gave the burger its pinkish hue and breadcrumbs improved its consistency.

This, the world's most expensive burger – the development of which was funded by Google co-founder Sergey Brin – had an "intense taste" said Hanni Rützler of the Future of Food Studio, who was the first to taste it at the event. "It's close to meat, but it's not that juicy. The consistency is perfect." She added that the lack of fat meant the centre of the burger was not as juicy as it might have been.

WHAT DO YOU THINK?

Let us know your opinions at facebook.com/sciencefocus and our forum at sciencefocus.com/forum

Marcus Vinicius Custodio *I would undoubtedly go for synthetic meat.*

@aaronmortimer *Put it in a Petri dish-grown tiger bread roll and you've got a deal!*

@geoffrey *I would. You've got to try moo things...*

@NexusJim *Yes! It's one of the only ways to sustain the ever growing human population... either that or a bug burger. Mmmm tasty!*

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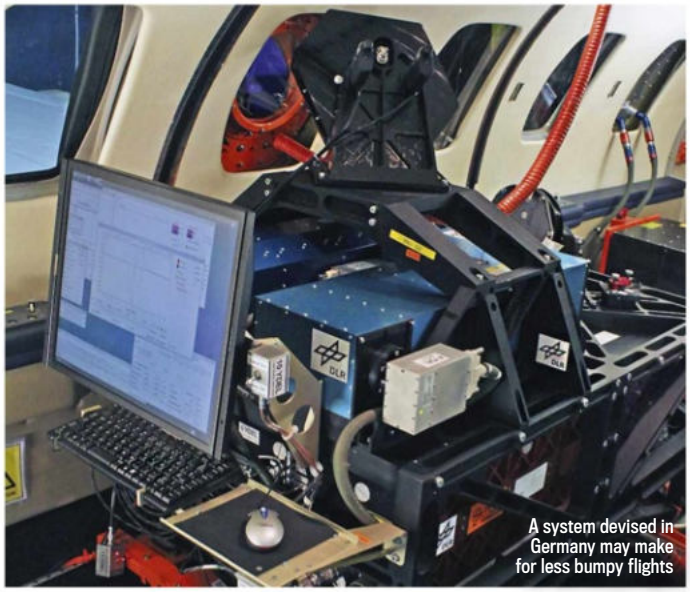


A system devised in Germany may make for less bumpy flights

Aeronautics

Lasers detect clear air turbulence

CLEAR-AIR TURBULENCE is invisible, deadly and can strike at any moment. But pilots may soon be able to spot it before it happens, thanks to a laser system being developed by European scientists.

Clear-air turbulence (CAT) occurs in apparently calm skies. It can cause a plane to plunge violently, jostling passengers and, in rare cases, causing fatal injuries. Aircraft most often encounter CAT near the edges of jet streams – fast, narrow air currents high up in the atmosphere. When the edge of a jet stream interacts with slower-moving air, it can create waves and vortices that alter the airflow over the aircraft's wings, causing sudden lurches.

There's currently no accurate way to detect CAT, but researchers at the German Aerospace Centre (DLR) are now testing a device that they hope will do just that. Their LIDAR (Light Detection and Ranging) instrument sends out ultraviolet laser rays in front of the plane. These reflect off air molecules and travel back to the instrument. By measuring the amount of back-scattered light, the system can estimate the number of air molecules and so calculate the density of the air ahead.

"Clear-air turbulence causes small fluctuations in air density," says Dr Patrick Vrancken at DLR's Institute of Atmospheric Physics. "By detecting these variations, we expect to spot turbulence up to 10-15km ahead, and we hope to increase this to 30km."

This would provide around two minutes' warning, giving pilots a chance to warn passengers to fasten their seatbelts, or even to plan a new route around the region.

"At the moment, our system is designed to work when the air is free from aerosols such as dust, sand and sea salt," adds Vrancken. "These pollute our measurements. Our next step is to develop a way to filter out this extra noise so that our system works in all atmospheric conditions."

JAMES LLOYD

PHOTO: GERMAN AEROSPACE CENTRE, APRIL ISCH/UNIVERSITY OF CHICAGO

CLICK HERE with Kelly Oakes

New websites, blogs and podcasts

DISCOVER VOYAGER

discovervoyager.com/voyager1.php

Follow Voyager 1's journey from Earth to the edge of the Solar System with this site created for the International Space Apps Challenge, led by NASA. To help you get to grips with just how far Voyager 1 is from Earth, you can see both its distance in kilometres, and how long a signal takes to get there.

CHRIS HADFIELD

bit.ly/HadfieldSound

Life on the International Space Station isn't all non-stop excitement. Hear some of the more mundane noises recorded by Canadian astronaut Chris Hadfield during his time in orbit – including the sounds of the space station toilet – and find out how the guitar he used to cover Bowie's *Space Oddity* got into space in the first place.

NATURE GRAPHICS

naturegraphics.tumblr.com

Exactly how do you go about drawing an invisibility cloak? Go behind the scenes with the graphics team at the journal *Nature* as they visualise difficult scientific concepts and make them understandable. If you like your science presented visually, you'll enjoy learning about the effort and thought that goes into making such images.

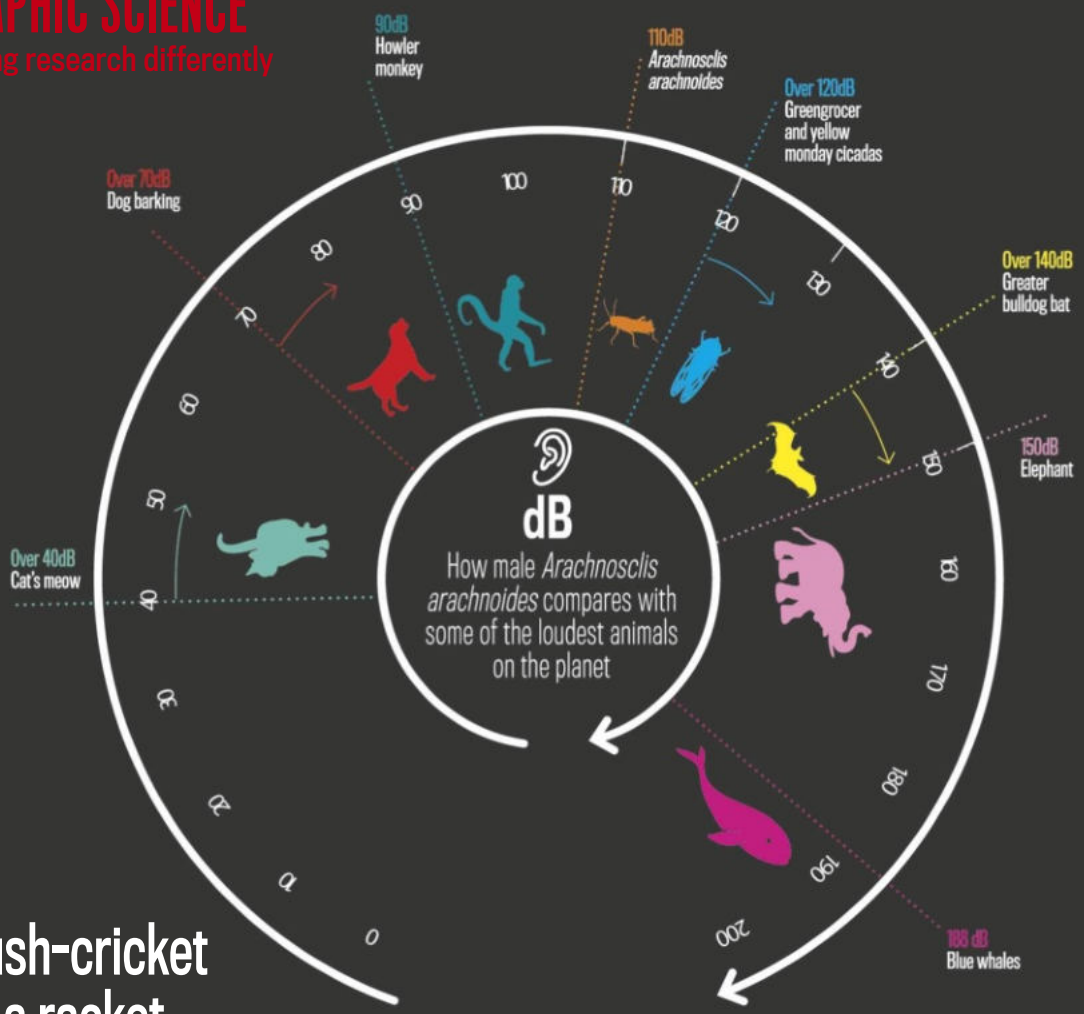
MINUTE EARTH

youtube.com/minuteearth

Minute Earth is a series of short, snappy animated films about our planet, tackling topics as diverse as where the hottest place on Earth is, what beer has to do with biodiversity and why we drive on the left while most European countries drive on the right. If you like this, then make sure to also check out creator Henry Reich's original – and still ongoing – YouTube series *Minute Physics*.

KELLY OAKES is a science journalist who tweets from @kahoakes

GRAPHIC SCIENCE
Seeing research differently



Tiny bush-cricket makes a racket

AN INSECT THAT was believed to be extinct until it was rediscovered in Columbia last year has been found to be one of the loudest creatures on the planet. When researchers at the University of Lincoln measured the calls of the bush-cricket, *Arachnosclis arachnoides*, they found that the males' songs can reach up to 110dB.

Much of the insect's song is ultrasonic – too high for human ears to detect – and so the researchers used ultrasound-sensitive equipment to measure how loud they are.

High-speed video showed the bush-crickets produce their calls by rubbing one wing against a row of 'teeth' on the other. But unlike most other species of bush-cricket, male *Arachnosclis* produce their calls as the wing opens, rather than as it closes.

NEWS IN BRIEF

Gut flora keep us special

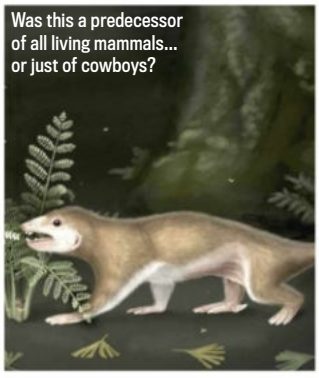
Gut bacteria may play an unlikely role in the origin of new species. Biologists at Vanderbilt University in the US analysed the gut microbes in two wasp species. When the two species were cross-bred, the hybrid wasps developed a new set of gut microbes that caused them to die. It seems microbes help keep the two species apart, allowing them to continue evolving separately.

Solar magnetic flip due

According to NASA, the Sun's magnetic field will flip over the next few months. But don't worry, this is just a regular part of the Sun's life cycle, occurring around once every 11 years. In fact, astronauts will be exposed to fewer cosmic rays because the electrical current that permeates space is disturbed while the flip is taking place, causing it to act as a shield.

Proto-mammal had spurs

A newly discovered fossil has provided the most detailed picture yet of a prototype mammal that lived 165 million years ago. The skeleton of rat-sized *Megaconus mammaliaformis*, found in China, sported spurs on the back of its heels, which may have contained poison. The creature had mammal-like features long before the first true mammals came along.


Was this a predecessor of all living mammals... or just of cowboys?

Nanotechnology

Nanorobots: coming soon to a cell inside you

Nanobots with mechanical parts might still be in the realms of science fiction, but DNA-based 'bots have already been put to work

SELF-ASSEMBLING NANOROBOTS that can home in on and deliver molecules to specific cells have been created in the lab and tested in a human blood sample. It's thought the system, described in a paper in the online edition of the journal *Nature Nanotechnology*, could be used to highlight diseased or malfunctioning cells in the body, and deliver therapeutic molecules to them.

Our blood contains various different cell types. In this proof of principle experiment, the tiny automata were designed to seek out just one of them, white blood cells, and attach a fluorescent tag to the cells' surfaces. But there's no reason why other cell types in the body can't be targeted, or the fluorescent tag replaced with a drug or a toxin. "This means we can design a system to target, treat or kill specific cells – cancer cells perhaps – without affecting similar healthy cells," says Dr Milan Stojanovic at Columbia University Medical Center, who designed the system. "This could help minimise side effects."

While similar nanorobots have been designed to deliver drugs to cells before, Dr Stojanovic's nanobots can pinpoint cells that don't have a single characteristic that identifies them. Cancer cells rarely have a single feature, such as a particular type of receptor, that sets them apart from others.

The tiny automata are made of discrete DNA-based ingredients which rapidly self-assemble into a functional unit when they interact with the cell of interest. Three of the components are DNA strands attached to antibodies. Each antibody recognises and binds to a different protein on the target cell. Once all three are in place, a fourth component then triggers a chain reaction within the assembled nanorobot. This sees a fifth component – here, a piece of DNA with a fluorescent maker – deliver its payload to the cell surface.

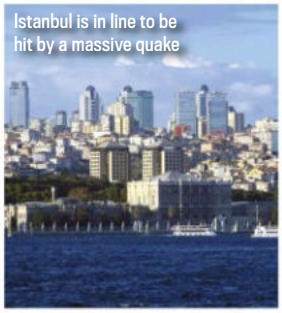
It's because this system targets combinations of three or four cell-defining proteins that it's so efficient at pinpointing specific cell types. Sometimes, cells can also be defined by the lack of a particular protein. With this in mind, the system can also be tweaked to recognise a cell that expresses two proteins, but lacks expression of a third.

HELEN PILCHER

PHOTO: SCIENCE PHOTO LIBRARY, THINKSTOCK, NASA X2

DOOMWATCH with Bill McGuire

The world's biggest natural disasters in waiting



Istanbul is in line to be hit by a massive quake

NORTH ANATOLIAN FAULT

Where: Marmara Sea, Turkey

THE NORTH ANATOLIAN Fault, which slices across northern Turkey, has been 'unzipping' bit by bit and from east to west since the 1930s, triggering destructive earthquakes that have been getting ever closer to the great metropolis of Istanbul. The last, a lethal magnitude-7.4 quake just 70km (43 miles) east of the city in 1999, took 17,000 lives. Now, researchers at Germany's Centre for Geosciences in Potsdam, have identified a 'locked' section of the fault beneath the Marmara Sea, south of Istanbul. This part of the fault is unmoving because it is accumulating the strain that will drive the next quake – expected to be magnitude 7 or bigger. Some estimates put the likelihood of a quake of this magnitude hitting Istanbul between now and 2030 as high as 65 per cent.

Nevado del Ruiz: a time bomb

NEVADO DEL RUIZ VOLCANO

Where: Central Colombia

IN 1985, THE Nevado del Ruiz volcano hosted the second biggest volcanic catastrophe since Krakatoa blasted itself apart in 1883. The eruption responsible was not huge, but hot flows of ash and gas melted the summit glacier, sending millions of tonnes of water cascading into the valleys below. Picking up debris as they went, the floods rapidly turned into mudflows that buried the town of Armero and other communities, taking 25,000 lives. After a quarter of a century of calm, small eruptions in 2012 led to increased concern. Frequent tremors during July this year point to fresh magma on the move again and there are worries that a new eruption is on the way. Half a million people are now thought to be under threat from mudflows.

Hurricane Katrina devastated New Orleans in 2005

NORTH ATLANTIC HURRICANES

Where: Caribbean, US east coasts

A NEW STUDY by the UK Met Office suggests that mankind's polluting activities may have had one positive impact. Between the start of June and the end of November every year, hurricanes are the scourge of the North Atlantic, with as many as 15 causing widespread devastation and loss of life in some years. According to the Met Office report, however, it seems things could have been worse. The authors show that hurricane activity in the 20th Century was suppressed to varying degrees by aerosols – tiny particles pumped into the atmosphere by power stations, factories, vehicles and the like. These acted to cool the North Atlantic by reflecting the Sun's energy back into space, making it more difficult for heat-loving hurricanes to form.

BILL MCGUIRE is Professor of Geophysical & Climate Hazards at University College London and the author of *Waking The Giant*

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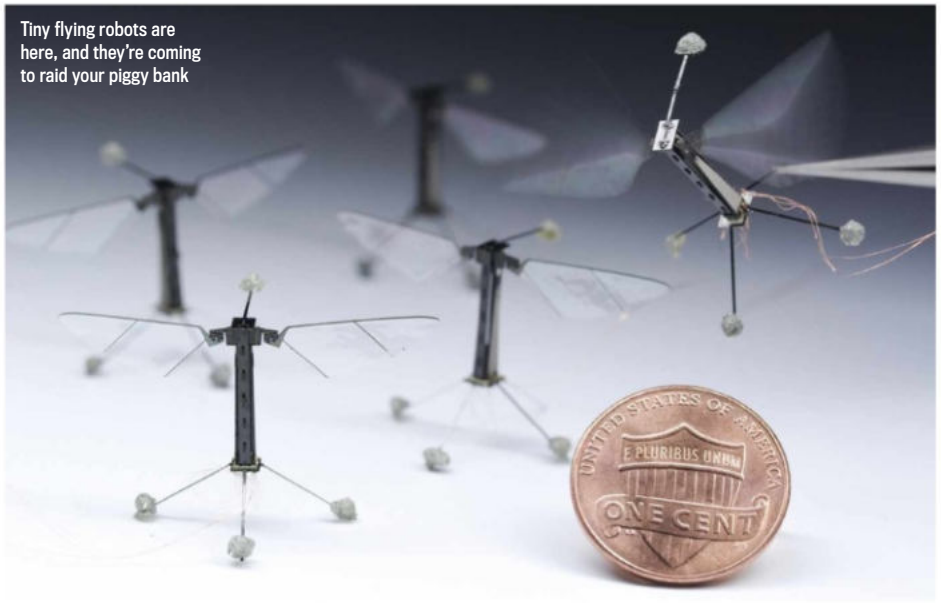

Tiny flying robots are here, and they're coming to raid your piggy bank

Robotics

Micro 'bot lifts off

HALF THE SIZE of a paperclip, an exceptionally agile flying robot could represent the future of search and rescue operations, or be used for artificial pollination. RoboBee comes straight from the cutting edge of micromanufacturing and can perform precise flight manoeuvres similar to those of a house-fly.

Researchers at the microrobotics lab at Harvard University in the US modelled RoboBee on the morphology of a fly in an attempt to duplicate the insect's aerial expertise. The 'bot represents the culmination of over a decade's work.

Key to RoboBee's precise manoeuvres are its wafer-thin wings. Thanks to piezoelectric actuators – strips of ceramic that expand and contact when an electric field is applied – the robot can flap its wings up to 120 times per second.

As it weighs in at only 80mg, the RoboBee is vulnerable to even the slightest changes in airflow, and so requires an unusually fast control system. The team's next challenges will be to develop tiny batteries and digital brains that would allow the 'bots to fly without being attached to a wire.

NATALIE KEIR

Marine biology

Dolphins recognise old friends 20 years on

"THEY CALL HIM Flipper/No-one, you see, is smarter than he." It turns out the 1960s TV theme tune isn't so far off the mark, as a new study reveals that dolphins can remember each other's signature whistles for decades.

Just as we have our own names, dolphins have their own unique signature whistle, a pithy signal that they respond to and use to communicate over long distances. Dr Jason Bruck at the University of Chicago in Illinois played the signature whistles of previous pool-mates and total strangers to 43 different captive dolphins, and found the marine mammals were able to recognise the calls of former friends up to 20 years after they had been separated.

Dolphins ignored the signature calls of unfamiliar animals. But when they heard the whistles of dolphins they had associated with previously, they swam straight towards the underwater speaker. Some whistled back and one mother dolphin even shepherded her calf towards the sound, to listen to the calls of a dolphin she'd once known.

This study suggests that dolphins form lifelong social memories. Their 20-year recall is the longest such memory ever recorded for a non-human animal.

HELEN PILCHER

Environmental science

Cactus-inspired needles could clean up oil spills

TAKING A TIP from the way cactus needles pull water from the air, researchers have designed tiny synthetic spikes that can remove oil from water.

Living in dry environments, cacti have evolved some nifty ways to collect water. Last year, researchers discovered that a cactus called *Opuntia microdasys* uses tapered spines to draw water from the air. When water droplets land near the tip of one of the spines, they're distorted into a flattened, clam-like shape. As surface tension in the droplets forces them back into a circular shape, it pushes them towards the base of the spine.

Inspired by this, researchers at the Chinese Academy of Sciences in Beijing made similar spines from materials including copper and a silicone polymer. When these were immersed in a mixture of oil and water, submerged oil droplets travelled towards the base of the needles at a rate of around 2mm per second. Using hexagonal arrays of silicone needles, the scientists were able to separate up to 99 per cent of the oil.

The system could provide a new way to clean up oil spills. "When oil enters seawater, some of it breaks down into smaller, microscopic droplets that are too dense to float," says Dr Thomas Azwell, an environmental scientist at the University of California, Berkeley, who wasn't involved in the research. "Current clean-up technologies only focus on the oil near the surface, but an array of needles submerged underwater could capture those oil droplets below."

JAMES LLOYD


Cactus spines have inspired a new system for cleaning up oil spills

PHOTO: KEVIN MA/PAKPONG CHIRARATTANANON, SCIENCE PHOTO LIBRARY

INSIDE SCIENCE

ROBERT MATTHEWS

Politicians need to rely on science not headlines to make decisions

THE ANNUAL RITUAL of putting the clocks back at the end of this month always puts me in a bad mood, and not just because of the darker evenings. It's an annual reminder of what happens when decisions are based on emotion rather than facts.

Specifically, it reminds me of an experiment that began in October 1968, when the Government ruled that the clocks were to be left on British Summer Time (BST) for three years, to find out the benefits of swapping lighter mornings for an extra hour of light in the evenings. Hardly had the experiment started than the media began carrying stories of kids being killed on the roads as they made their way to school in darkness. It seemed as if the experiment was a catastrophic mistake.

But the statisticians monitoring the outcome weren't so sure. They saw the experiment as an exercise in something politicians now trumpet all the time: evidence-based policymaking. And when the data emerged, it revealed something startling. While the number of road deaths in the darker mornings had indeed increased, it was more than cancelled out by the reduced deaths in the evenings. The statisticians estimated there was a net saving of around 2,500 deaths and serious injuries over the winter.

Yet it made no difference. A few months after the publication of the data, the experiment was stopped. The politicians couldn't cope with the fact that the statistical benefit was just that: a statistic. No-one could actually point to 2,500 people and say they'd dodged calamity by the switch to lighter evenings. In contrast, the media had no trouble at all finding actual families whose loved ones had been killed through the accidents in the mornings.

Scientists had to wrestle with politicians when it came to a British Summer Time experiment; the politicians won

"Hard evidence often loses out to tabloid sentiment when politicians are trying to decide policy"

So the objective reality lost out to the emotional response whipped up by the media. And that has led to thousands of lives being lost unnecessarily over the last 45 years. Even today, hard evidence often loses out to tabloid sentiment when politicians are trying to decide policy. In the late 1990s, the government had another shot at putting evidence at the heart of policy decisions by setting up what is now called the National Institute for Health and Care Excellence (NICE), to decide which new therapies are fit for use by the NHS.

This isn't just a matter of checking that the therapy actually works; it also has to be cost-effective. And that means weighing the cost of the therapy against the benefit to the patients. Inevitably, NICE has often found itself harangued by patient support groups for refusing to approve some expensive wonder-drug whose benefits simply aren't cost-effective. In some cases, such as the breast-cancer drug Herceptin, the support groups have teamed up with the media to force ministers to overrule the evidence-based decisions of NICE. The result was stories crowing about victories for patients and the media – while ignoring the fact that in a cash-strapped health service, that meant less money for proven therapies that benefit more patients.

Then there's the flip-side, where ministers refuse to cave in, despite evidence that they're wrong. This has long blighted policy on issues with a 'public morality' element, like alcohol and recreational drugs. For years, ministers have been told that the dangers of drugs like ecstasy have been overplayed, while those from alcohol need more attention. And for years, ministers have chosen to ignore the evidence for fear of a tabloid backlash about being 'soft' on drugs.

No-one is saying that deciding policy is easy. Nor are scientists always right. But ministers should have more faith in science, and worry less about headlines. First, it would increase their chances of making the right decision. And second, when some policy does prove incorrect, they'll be able to say the original decision was based on the best available scientific evidence. Which sounds a bit more statesmanlike than saying it was based on getting positive coverage in *The Sun*. ■

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham

ILLUSTRATOR: STEPHEN COLLINS

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EVERYDAY SCIENCE

HELEN CZERSKI

Spilled your coffee? It's an opportunity to explore the strange world of molecules

COFFEE STAINS ARE weird. You'd think that spilled coffee would leave behind a uniform dark patch, but it doesn't. Instead, you get a dark ring outlining where the coffee spill was, an accusatory record of your clumsiness. It's a bit like a line drawn around a body at a crime scene. I don't drink much coffee, but I made some today and I've been playing with it all morning. A large flat ceramic dish is sitting in the kitchen, decorated with the blobs and circles. I'm enjoying this game, because it lets me play with some of the tiny forces that are moving the microscopic world around. We can't see them directly, but the coffee is dancing to their tune.

We think of coffee as being a magical witch's brew, full of mysterious ingredients that might perk us up, make us irritable, improve short-term memory, stop us sleeping and draw us into caffeine addiction. Actually, it's mostly water. Only 1 per cent comes from the coffee plant, and those molecules are carried along by the water like a sneaky stowaway. When the coffee sloshes onto the table, it behaves just like water normally does. It stays in a patch, held in at the edges by surface tension.

I've been trying to draw a teddy bear. I've put circular droplets next to each other to make a coffee spill with a rotund tummy, ears worthy of Mickey Mouse, and one leg bigger than the other. It's warm, so the water starts to evaporate. Tiny molecules drift off into the atmosphere from all over the top of the spill. You'd think the coffee patch would shrink. But it doesn't. By a quirk of surface science, the edges have to stay where they are. They're stuck on the rough surface. So to refill the edges of the shape, coffee has to travel outward from the centre until it gets to the edges. As I watch my bear-shaped blob, an invisible slow conveyer belt of coffee is crawling from his tummy towards his ears and legs.

Surface tension and capillary action can turn a coffee stain into a work of art

At the edges, the water evaporates, but the freeloading coffee can't. Tiny coffee particles build up at the edge of the spill, because they have nowhere else to go. The forces keeping the edges of the shape in place are so strong that the centre of the spill is completely emptied out. Almost all the coffee in the spill is now stuck at the edge of the shape. My teddy bear has become a line drawing.

"Tiny forces between molecules can move water around, and we get hints of that hidden world by just letting a coffee spill sit"

Tiny flows like this happen all around us, and we rely on them. The bonds between water molecules are really strong, and if there is a stronger pull in one place than another, the water will flow until all the forces are even. It's called capillary action, and it's most noticeable when there's a really narrow space that water can squeeze in to. Water is 'sticky', and it'll stick to some surfaces and crawl along them, pulling other water with it. This is what happens when water is absorbed by paper towels, when clothing wicks sweat away from your skin, and it's how trees transport water up their trunks.

Society would probably frown on someone of my age spilling coffee deliberately, but I think we should all play with our food more. I like the thought that the tiny forces between jostling molecules can move water around, and that we can get hints of that hidden world by just letting a coffee spill sit for a bit. Anyway, I never liked drinking the stuff so it might as well provide entertainment. I've nearly got enough for a teddy bears' picnic... ■

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter who appears regularly on *Dara O Briain's Science Club*

ILLUSTRATOR: GEMMA ROBINSON

THE UNIVERSE

THE STORY SO FAR

How new discoveries are rewriting the history of our cosmos

Words: Stuart Clark

ILLUSTRATOR: MAGICTORCH

THIS YEAR COULD go down in the astronomical textbooks as the one when a revolution in our understanding of the Universe began. The iconoclast at the centre of this upheaval is not a person but a machine: a space probe called Planck. Named after the great German physicist Max Planck, the spacecraft was launched by the European Space Agency (ESA) in 2009, tasked with detecting the 'blueprint' of the Universe – a snapshot of the seeds of the stars and galaxies that surround us today.

For almost a century, cosmologists have been busily constructing mathematical theories that describe the story of the Universe from the earliest moments to the present day. But now, analysis of Planck's blueprint is revealing a number of plot holes, or 'anomalies' as the scientists call them, that don't seem to fit the story.

For one thing, data from Planck indicates that the Universe is older than expected by about 50 million years. It also contains more of the mysterious dark matter and fewer atoms than previously thought. And while these may sound serious, in reality they are the least of a cosmologist's worries.

Much more troubling is the so-called 'cold spot' in the radiation from the early Universe that Planck has recorded – a region that looks significantly colder than current theories allow. Indeed, the temperature pattern across the whole Universe looks strangely lopsided.

New discoveries such as these are shedding new light on the history of our Universe: the story of how we arrived at the cosmos we see around us today.

CHAPTER ONE:
THE BIG BANG

THE VERY MOMENT of the Big Bang remains shrouded in as much mystery as ever. It's the point at which the Universe began – space and time were formed and all the matter and energy that we see around us somehow came into existence. Data from the Planck telescope now indicates this happened 13.82 billion years ago. Initially, there were no stars or galaxies, just a hot, dense sea of particles and radiation.

Straight after the Big Bang, space began to expand, spreading out the matter and energy. The trouble is the theory that we use to understand the expansion, Einstein's Theory of General Relativity, will not work at the extreme densities of the Big Bang and so physicists are searching for a way to extend it.

The best template is quantum theory, which deals with the physics of the very small and provides a basis for all the forces of nature, except gravity. To investigate such a theory, scientists must turn to the Large Hadron Collider (LHC) at CERN in Switzerland, which recreates the conditions thought to have been present in the Universe a fraction of a second after the Big Bang. "The LHC gives us a mini-Universe in the laboratory," says Dr Anupam Mazumdar, a cosmologist at Lancaster University. While the experiment can show what particles were prevalent in the primordial Universe, theoreticians then have to form a theory to understand them.

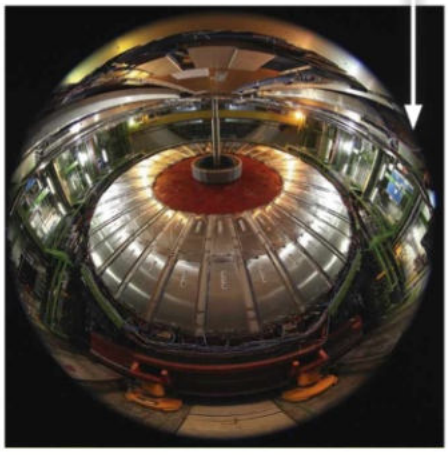
String theory is a possible quantum theory of gravity, but it is unclear whether it bears any resemblance to reality, because the mathematics are currently unable to predict anything that can be tested in a laboratory or observed in the Universe.

So for now, the moment of the Big Bang remains terra incognito.

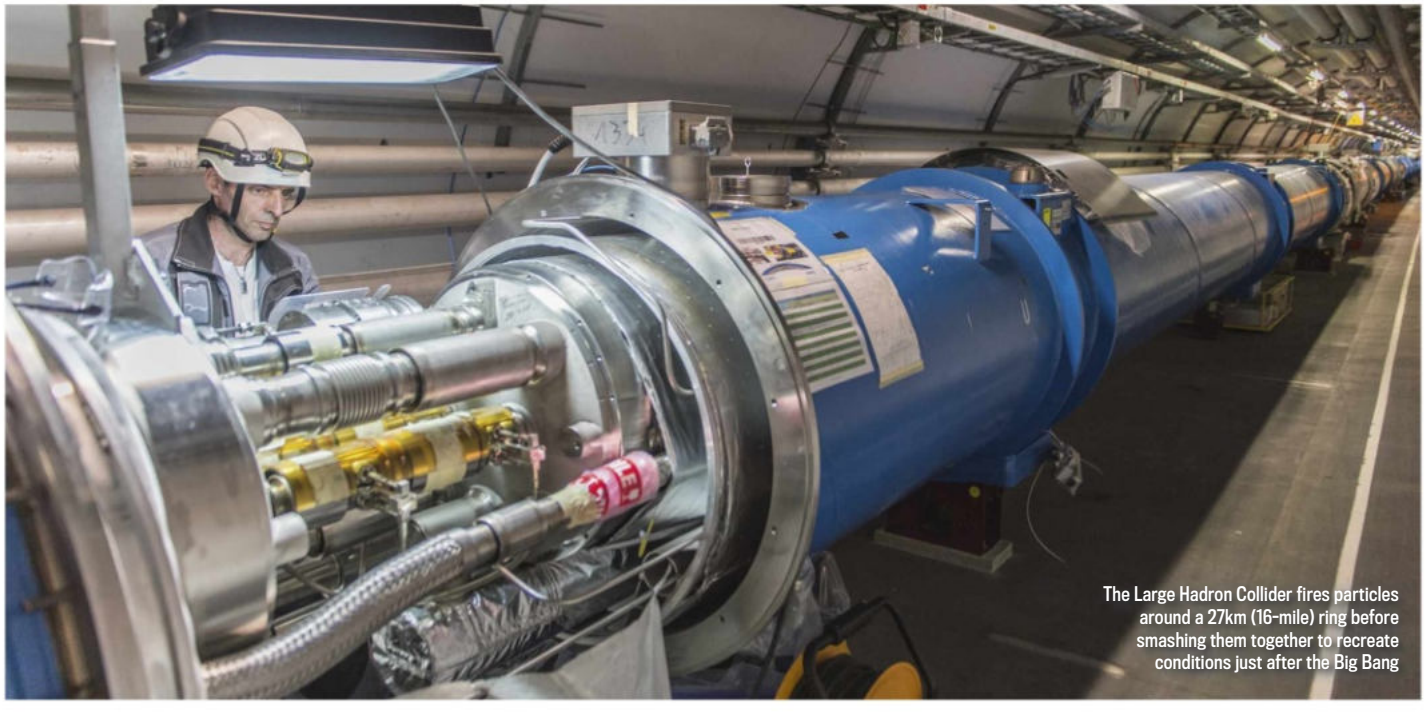
CHAPTER TWO:
INFLATION
10^{-35} seconds after the Big Bang

UNTIL PLANCK, ALMOST every observation of the Universe's largest scales had suggested that it is remarkably uniform. Sure, there are clusters of galaxies and huge voids, but even these are pretty small when the Universe as a whole is considered.

As a result, cosmologists had developed a mathematical framework called inflation to explain the uniformity. First proposed in 1980 by Alan Guth, a particle physicist from the Massachusetts Institute of Technology, it postulated that right after the Big Bang a period of extraordinary expansion took place. In the blink of an eye, the Universe grew bigger by a factor of at least 1,060. This would smooth out



The CMS detector at the Large Hadron Collider (top, below) is looking for particles that could make up dark matter



The Large Hadron Collider fires particles around a 27km (16-mile) ring before smashing them together to recreate conditions just after the Big Bang

PHOTO: CERN X3, NASA

PLANCK'S POSTCARD FROM THE PAST

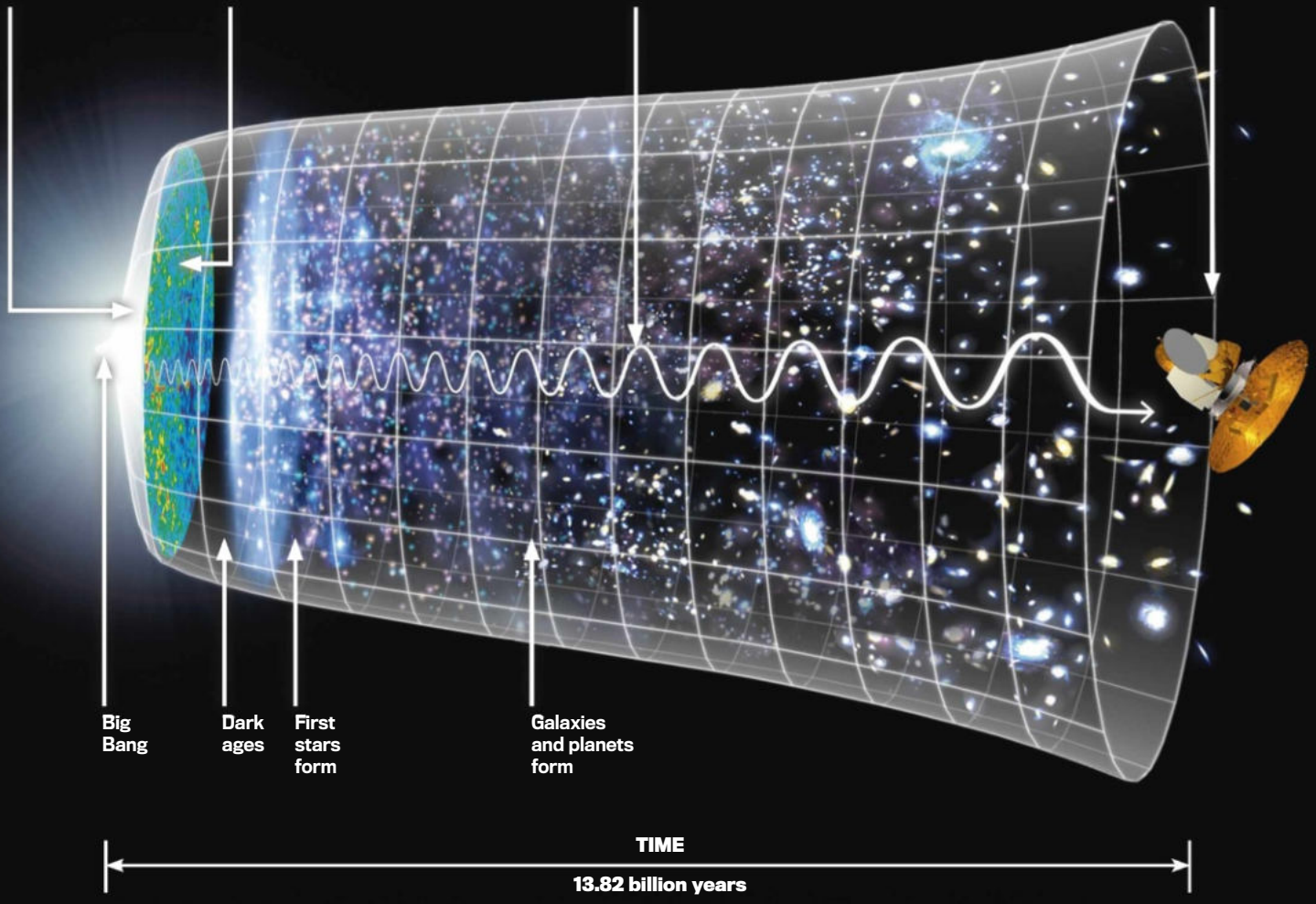
How detecting radiation that's travelled billions of years provides a window into the early Universe

1 Radiation and matter are produced by the Big Bang, but are locked together in a hot plasma.

2 When the Universe cools sufficiently, the radiation and matter go their separate ways. It's this radiation that forms the cosmic microwave background (CMB).

3 The microwave background was first released as visible light but the expansion of the Universe has stretched it and turned it into microwaves.

4 The microwave radiation travelled across space for billions of years before reaching the Planck spacecraft. The observatory built up a map of this CMB.



FROM A POSTCARD TO PROFOUND CONCLUSIONS...

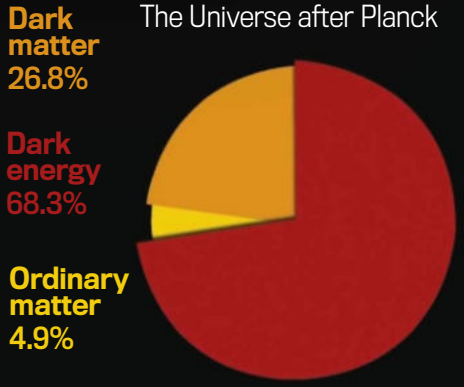
PLANCK'S DATA CAN tell cosmologists the age of the Universe in a roundabout way. Unfortunately, it is not as simple as just measuring it. Instead, scientists try to reproduce the Planck map in a computer simulation. This involves programming what cosmologists think the Universe contains into a supercomputer, such as the University of Durham's aptly named Cosmology Machine, and then fiddling with the various proportions until they get something that looks like the actual map.

In doing this, the Planck scientists announced in March that there appears to be 68.3 per cent dark energy instead of the expected 72.8 per cent, and 26.8 per cent dark matter rather than the 22.7 per cent previously thought. The percentage of atoms changes slightly from 4.5 per cent to 4.9 per cent. The earlier figures came from NASA's Wilkinson Microwave Anisotropy Probe.

From the total matter content of the Universe, you can then work out the expansion rate, known as the Hubble Constant. And from this you can work out the age of the Universe.

There is a caveat, however. If cosmologists are wrong in their assumptions that dark matter and dark energy exist, then these figures are all totally wrong.

The Universe after Planck



WHAT IS DARK MATTER?

The invisible stuff makes up over a quarter of our Universe

ASTRONOMERS AS FAR back as the 1930s began to suspect that there was more matter than could be seen in the Universe. Today they believe it is subatomic particles that were potent in the early moments of the Big Bang, but have now virtually lost their ability to interact with normal matter, except through gravity.

In modern cosmology, dark matter is needed to help galaxies form and to keep them spinning at the rate observed by supplying extra gravity. The trouble is, there is no conclusive detection of a dark matter particle to confirm its existence. There are a number of tentative detections from the various dark matter experiments around the world, such as Xenon in Italy and CDMS in America, but nothing that looks quite what theoreticians were expecting.

Regardless, Dr Rose Lerner, a cosmologist at the University of Helsinki, Finland, is not too bothered. "These experiments are looking for a very specific type of dark matter with a specific way of interacting, but dark matter could be anything."

So, the message is keep calm and carry on looking. However, a small group of cosmologists think that dark matter does not exist and instead we are misunderstanding the way gravity works. If this were the case, we would have to modify Einstein's Theory of General Relativity.

A detector is checked at the Cryogenic Dark Matter Search (CDMS) experiment deep underground in Minnesota

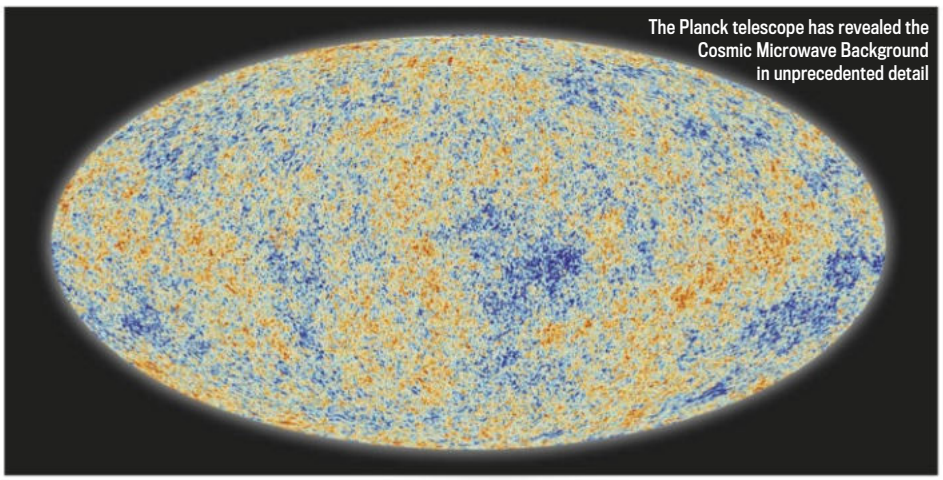
any large-scale deviation across the Universe, making it appear uniform. Only the smallest fluctuations in the density of matter and energy would remain, the cosmologists theorised. Remarkably, these fluctuations were found in 1989 by NASA's COBE satellite, and they amount to no more than one part in 100,000. They are the seeds from which the galaxies have grown.

Planck has measured these fluctuations in much greater detail. The £500 million spacecraft split the sky into a billion pixels and observed each one a thousand times during its three-year mission. This produced a map of the sea of microwaves that bathe all of space – the cosmic microwave background (CMB) – unlike anything that had been seen before.

It is these subtle fluctuations in this radiation left over from the Big Bang that provide astronomers with their blueprint of the early Universe – the distribution of matter and energy a fraction of a second after the Big Bang. When the data from Planck was released in March, it immediately became clear that there are problems that the cosmological community are still trying to come to terms with.

There is a suspiciously large cold spot signalling that a vast clump of matter was present in the early Universe and it is much denser than inflation can explain. More troubling is that there is one side of the Universe where the fluctuations appear stronger than the other, indicating an uneven distribution of matter across the whole Universe. "This is very strange," says Dr George Efstathiou, Professor of Astrophysics at the University of Cambridge and a member of the Planck science team. "And I think that if there really is anything to this, you have to question how that fits in with inflation. It's really puzzling."

But it may not spell the end for the theory of inflation just yet. "Instead, my gut instinct is that these anomalies will point to a more specific model of inflation," says Dr Rose Lerner, a cosmologist at the University of Helsinki in Finland who works independently of the Planck consortium.



The Planck telescope has revealed the Cosmic Microwave Background in unprecedented detail

PHOTO: FERMILAB, SCIENCE PHOTO LIBRARY X2, NASA

Another solution to the anomalies, according to Matthew Kleban of New York University, is that during the sudden expansion that happened during inflation, our Universe slammed into a neighbouring one. This sent shockwaves rippling through our cosmos that imprinted the anomalies we see today. If so, we should think of them as a cosmic bruise. Testing such a controversial idea, however, is very tricky.

CHAPTER THREE:
PARTICLE CREATION
1 minute after the Big Bang

AT ONE MINUTE old, the entire Universe resembled the interior of a star but on a vast scale. Particles that would become the nuclei of all the atoms in the Universe were built in this cauldron. Mostly these were single protons that would become hydrogen, but about a quarter of the particles turned into helium nuclei, containing two protons and two neutrons. There were also trace amounts of lithium and beryllium produced.

The evidence for all of this furious activity is all around us today in the chemical make-up of the Universe. We know from measurements of the radiation given off by our Sun and other stars that 98 per cent of the Universe remains in the form of this primordial hydrogen and helium. Only 2 per cent of the original atoms have been processed into heavier chemical elements while inside stars.

CHAPTER FOUR:
THE DECOUPLING OF MATTER AND ENERGY
380,000 years after the Big Bang

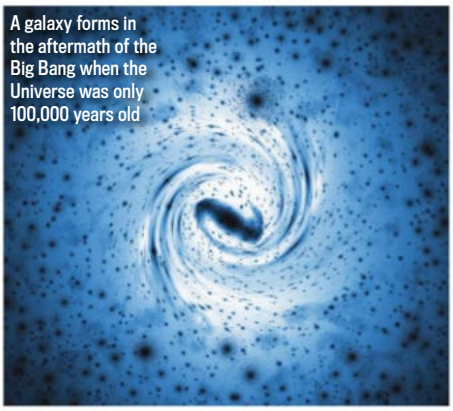
THIS IS THE moment when the radiation detected by Planck was released into space. Until then, the Universe had been a searing mass of atomic nuclei, lighter particles and energy. It had been impossible for whole atoms to form because whenever a nucleus and an electron particle bonded together, the torrent of radiation smashed them apart again.

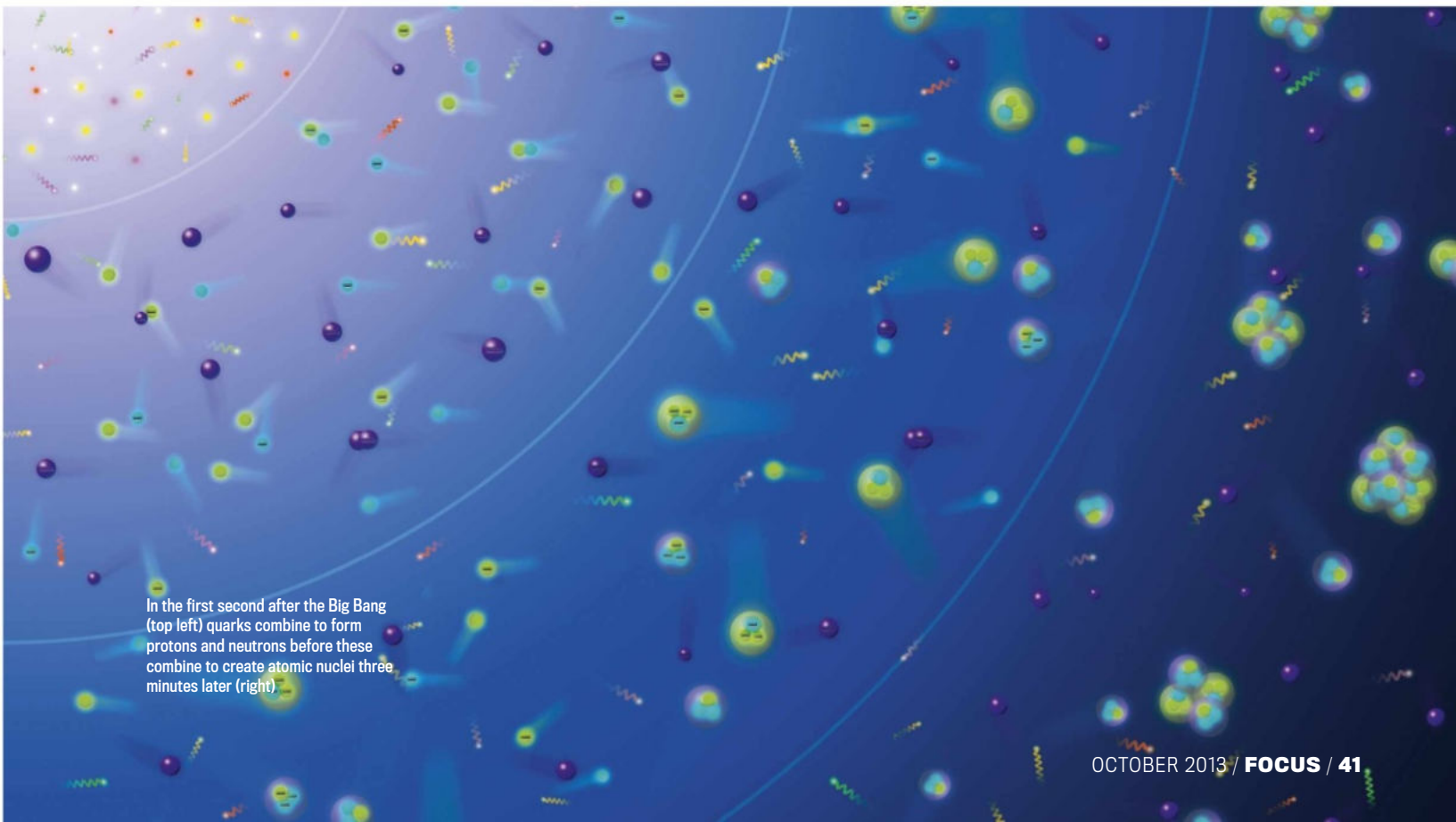
Now, the continual expansion of space weakened the radiation so much that it could no longer break apart the atoms. This was a watershed moment because, with most of the previously free particles now confined into atoms, it was as though the fog cleared.

In the same way that we can see to the horizon on Earth on a clear day, so we can now see this radiation that has spent almost 14 billion years travelling across space, preserving a record of the density of the various clumps of matter that became galaxies. It's this record that's providing troubling insights into the inflation that went before.

CHAPTER FIVE:
THE COSMIC DARK AGES
1 million years after the Big Bang

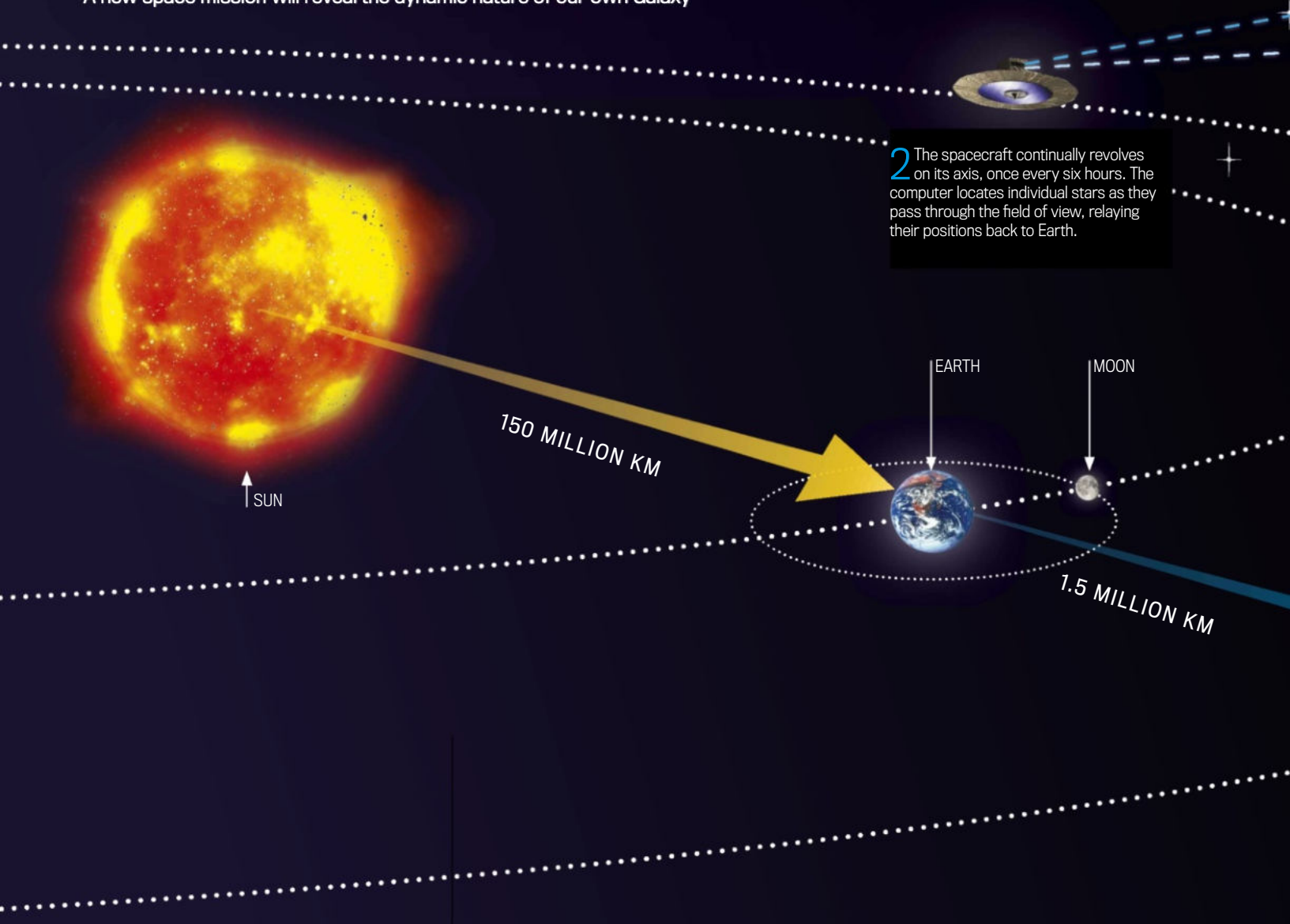
INITIALLY THE DECOUPLED radiation would have been visible to the human eye, not that there were any humans around to see it of course. But the continued expansion of space stretched the


A galaxy forms in the aftermath of the Big Bang when the Universe was only 100,000 years old


In the first second after the Big Bang (top left) quarks combine to form protons and neutrons before these combine to create atomic nuclei three minutes later (right)

THE HISTORY OF OUR COSMIC BACK YARD

A new space mission will reveal the dynamic nature of our own Galaxy



A HISTORY OF the Universe wouldn't be complete without a dig around our astronomical back garden. The Milky Way, our home Galaxy, is home to a few hundred billion stars, and we'd like to know how it was built. It might even be the best place to find clues to the nature of that most elusive substance, dark matter.

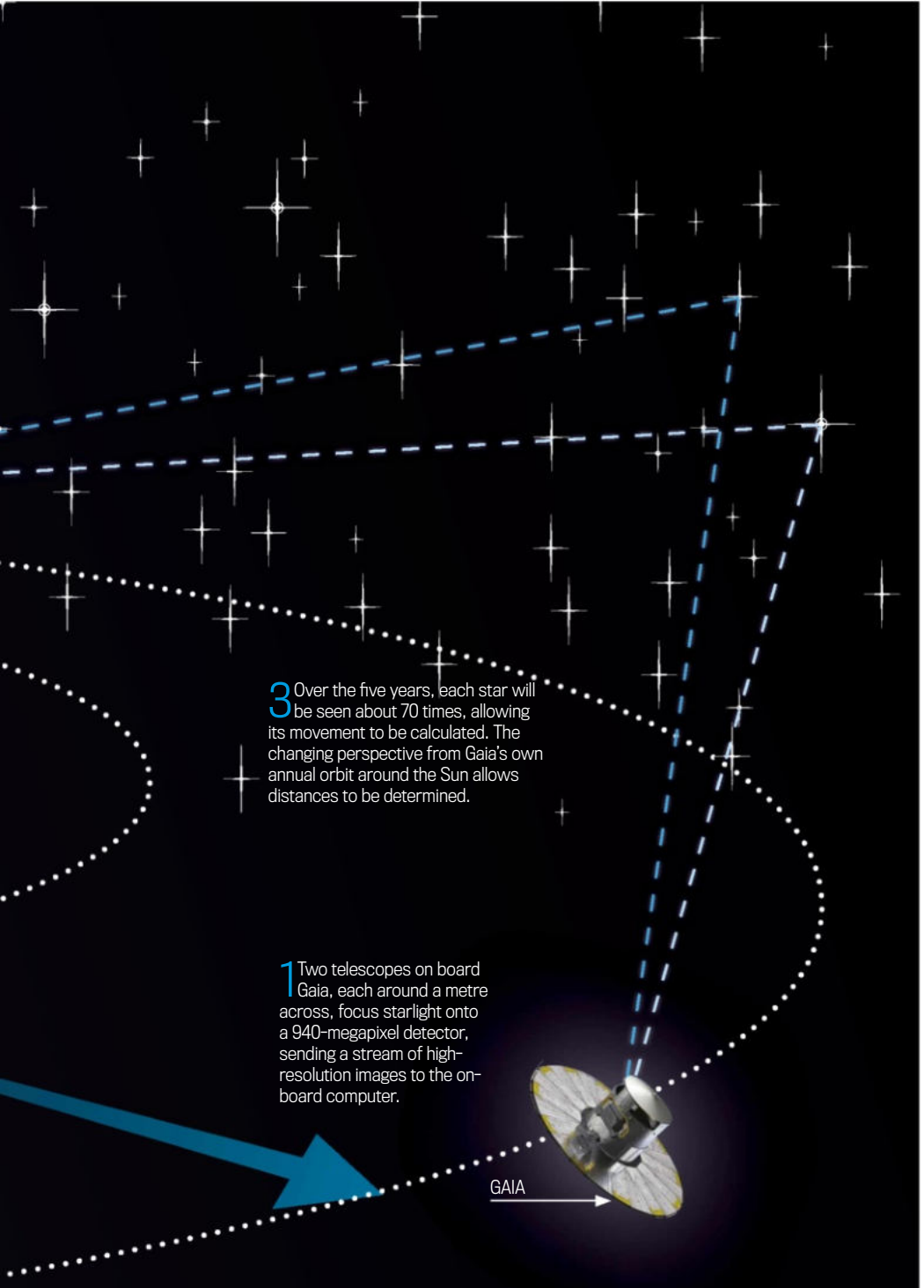
Gaia – the European Space Agency's latest telescope – is scheduled for launch from French Guiana late in November, after which it will be in orbit around the Sun, 1.5 million km (932,056 miles) from Earth. There it will build up an exquisitely detailed picture of the stars in our Galaxy.

Forget 3D: Gaia will compile a fully fledged map in no fewer than six dimensions, by tagging each star with three position co-ordinates and a further three detailing speed and direction. If current thinking is correct, the final 6D chart will be enough to prove that the Milky Way was assembled from dozens of smaller galaxies.

That's not an easy task: the Milky Way today looks smooth, with no clear sign of a mish-mash of different ingredients. Galactic mixing should go at a leisurely pace, so if Gaia compiles its data accurately enough, we can separate the stars into their original, long-lost mini-galaxies.

Dr Fernando Gomez of Michigan State University has been making predictions for what Gaia will find in the spherical halo of ancient stars surrounding the main galaxy. "If we look at halo stars, most of them are supposed to come from smaller galaxies that fell in. It can be anything from a few tens to hundreds of galaxies contributing," he says. If we can find partially mixed fragments of galaxies anywhere, it'll be here.

Gaia's advanced design and isolated orbit will let it pinpoint the location of stars to an unprecedented accuracy of 20 micro-arcseconds. If your eyes were that powerful



you'd be able to locate features on the Moon to within four centimetres. Even so, Gomez warns: "If you only look at positions in the sky, all the torn up little galaxies overlap with each other. Only with speeds can we tell they were once separate." Once we can accurately measure positions, the speeds of stars become measurable.

Even then we're only recording the apparent positions on the sky – working out the distance to a star is a more subtle business. Gaia does it by monitoring tiny parallax effects as it orbits the Sun. In other words, its changing vantage point is used in the same way that having two eyes gives you depth perception.

As well as confirming ideas of how galaxies form, Gaia will let us infer the distribution of dark matter. The motion of stars is dictated by gravity generated by matter. Stars speed up in dense regions, even if the mass is in the form of dark particles. So Gaia isn't just about history; it will study the make-up of the Universe too.

DR ANDREW PONTZEN is a cosmologist at University College London

"At one minute old, the entire Universe resembled the interior of a star but on a vast scale"

radiation into the infrared and then into the microwave.

The Universe became dark. Even after a million years, there were no celestial objects, so no sources of light. These were the Cosmic Dark Ages. Slowly the sea of atoms across the Universe began to fragment into clumps, pulling themselves together to become the first celestial objects. This was driven by the gravity of 'dark matter' clouds composed of particles that formed shortly after inflation (see 'What is dark matter?', on p40).

The Cosmic Dark Ages ended with the first celestial objects. These could have been stars or black holes. The first stars were purely hydrogen and helium, and some could have been hundreds or even thousands of times the mass of the Sun. They lived for just hundreds of thousands of years before destroying themselves and seeding the Universe with the heavier elements needed to form planets and life.

In March 2013, the Hubble Space Telescope pinpointed one of the Universe's oldest stars right on our celestial doorstep. Known as the Methuselah star, it has an estimated age of 14.5 billion years – give or take 0.8 billion years. It's only this margin of error that means it is potentially consistent with the supposed age of the Universe. This might sound like the star is older than the predicted age of the Universe, but is more of a quirk of how accurate we are able to measure the age of a star. It is speeding through space, just 190 light-years away, and astronomers think that it was once part of an ancient galaxy that embedded itself in our own, the Milky Way (see 'The history of our cosmic back yard', opposite).

The first black holes were those now found at the centres of galaxies. Although a black hole emits no light, matter falling into its gravitational clutches does heat up and emits radiation. They would have ended the Cosmic Dark Ages as surely as the first stars.

The first galaxies, known as quasars, were voracious monsters. Their feeding black holes gave out as much light as their collections of stars. Gradually,

THE DARK ENERGY MYSTERY

The force that's making our Universe grow faster remains as elusive as ever

WHEN IT COMES to puzzles that make cosmologists scratch their heads, they don't get any bigger than dark energy. It makes up about two-thirds of the Universe, yet we have no idea what it is. In the mid 1990s, astronomers discovered that the Universe's expansion has been speeding up. This was completely against their expectation; they thought it would be slowing down as gravity resisted the movement. Dark energy represents a kind of antigravity.

It could be an unexpected energy in the vacuum of space, or it could be a new force of nature. Either way, it means that we have to fundamentally rethink our understanding of the Universe. A third possibility is that we are getting the sums wrong. Cosmologists can only solve the equations of General Relativity if they assume an average density of matter across the Universe. If there are large variations of density, then the Universe will expand at different rates in different parts of space. As we look out across these regions, it could look to us as if the Universe is accelerating in the modern day. This is a controversial idea. Most cosmologists favour one of the first two options. ESA's 2020 mission Euclid will investigate all three ideas.

ESA's Euclid mission will investigate three theories that try to solve the mystery of dark matter

the black holes consumed all the matter in their vicinity, leaving only the stars to shine within the galaxy.

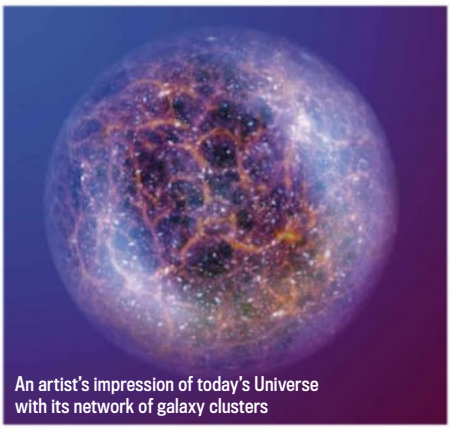
CHAPTER SIX: PRESENT DAY

13.8 billion years after the Big Bang

FROM THE TIME of the quasars until now, the Universe has been growing steadily. Occasionally, galaxies still collide and merge, but these incidents are a pale fraction of the number of cosmic smash-ups that used to take place. Star formation is also significantly reduced in the modern Universe. But don't go thinking that the Universe became boring.

The biggest mystery for cosmologists to solve manifested itself about five billion years ago. A strange energy began to accelerate the expansion of the Universe. Astronomers call it dark energy but don't ask them to explain it, yet (see 'The dark energy mystery', above).

"If I'm perfectly honest about it," says Dr Tony Padilla, a cosmologist at the



An artist's impression of today's Universe with its network of galaxy clusters

PHOTO: NASA X3, SCIENCE PHOTO LIBRARY X3

"The biggest mystery for cosmologists to solve manifested itself about five billion years ago"

'V'-shaped IC 3184 is two galaxies ploughing into each other. Collisions like this were far more frequent in the early Universe

University of Nottingham, "we're nowhere near to understanding what it is." Taking quantum physics as a starting point predicts a strength for dark energy that is monstrously large compared to what is observed. "It really makes no sense, and it's a problem that's been swept under the carpet for too long," says Padilla.

But maybe not for much longer: ESA is busy developing the Euclid mission, slated for launch in 2020. It will investigate with extreme precision the way in which the Universe is expanding as a means of determining the precise effect of dark energy and, in doing so, providing an important clue as to what it is.

Clearly, the story of the Universe has not yet reached its conclusion. And with the rate of new discoveries gathering pace, make sure you stay tuned. ■

DR STUART CLARK is an astronomer, journalist and author of *The Sky's Dark Labyrinth* trilogy

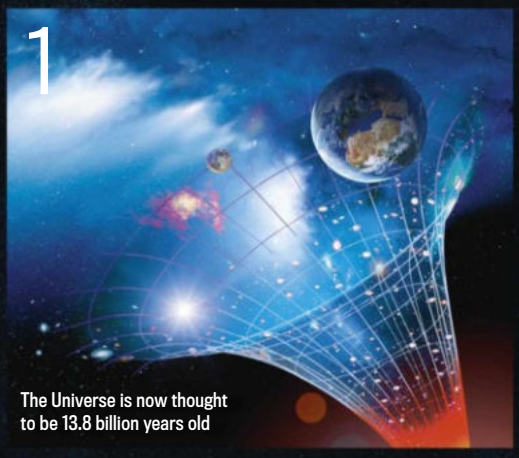
Find out more

Listen to *In Our Time – The Age of the Universe* on BBC Radio 4
http://bbc.in/LNnjG0

Cosmologist Sean Carroll discusses time and whether we live in a multiverse in a TED talk.
http://tinyurl.com/n3cqkjy

3 COSMIC CONUNDRUMS

We consider ourselves an intelligent species, but we don't know what 95 per cent of the Universe is or its age; here's why we're still in the dark



The Universe is now thought to be 13.8 billion years old

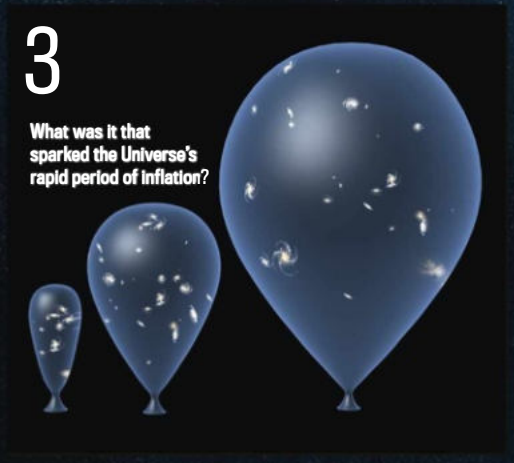
THE AGE OF THE UNIVERSE

Astronomers had felt pretty confident that they knew the age of the Universe. Derived from measuring exploding stars across the length and breadth of it, the figure they had settled on was 13.7 billion years. This work had been honed over decades, so it came as something of a shock when the Planck telescope showed that the Universe is more likely to be 13.8 billion years old. "It's slightly surprising, but I think that every time you measure more precisely you should expect the central value to move a little," says Dr Rose Lerner, of the University of Helsinki, Finland.

Dark energy is powering the expansion of the Universe, driving clusters of galaxies apart

NATURE OF THE DARK ENERGY

It is the biggest conundrum facing modern physics. Observations say that dark energy makes up about two-thirds of the contents of the Universe. Quantum theory says that it should be vastly more. To make matter worse, no-one has a clue what it is. Most observations suggest that it is some form of energy but some data is hinting that it could be an unanticipated force of nature. "That would be a game-changer in terms of what comes next," says Dr Tony Padilla at the University of Nottingham. "We may be able to construct experiments to investigate a new force."



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No one can find a solution to what sparked inflation – the extremely rapid growth of the Universe that took place after the Big Bang. Scientists would like to find the answer in particle physics. However, this is difficult because the sudden expansion of the early Universe took place at vastly larger energy levels than can be achieved in a particle accelerator such as the LHC, the most powerful ever built. The hypothetical particle responsible is called the 'inflaton'. Some scientists believe that it is the Higgs boson, but this is far from proven.

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HOW TO S A SPACE DIS

PHOTO: WARNER BROTHERS

URVIVE ASTER

With the new film *Gravity* featuring two astronauts whose spacecraft is hit by debris, what are the real dangers posed by exploring the high frontier?

Words: Kelly Oakes

TWO ASTRONAUTS FLOAT in space, working on the Hubble Space Telescope. Suddenly, a rogue piece of satellite crashes into the Space Shuttle that got them there. Hubble is hit by a piece of debris, too, knocking it out of its orbit. As the Shuttle is destroyed, the robotic arm that astronaut Ryan Stone is tethered to begins spinning out of control. She frantically tries to detach from it, just managing to set herself free. The Shuttle falls and Dr Stone is left floating in space, along with astronaut Matt Kowalsky. Contact with Houston is lost – the two astronauts are alone.

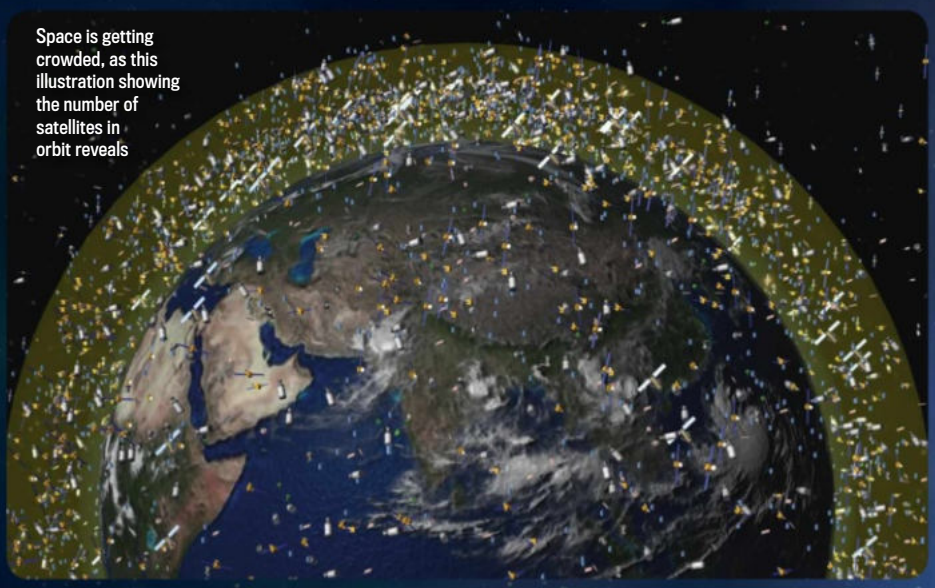
That's the premise of a new film called *Gravity*, which will hit cinemas on 11 October, starring Sandra Bullock as medical engineer Dr Ryan Stone and George Clooney as veteran astronaut Matt Kowalsky.

FACT OR FICTION?

This scenario may be fiction, but how close to reality is it? Astronauts who go to space today don't travel on the Shuttle, and it's the International Space Station (ISS) rather than Hubble that's the setting for today's space walks. A satellite roughly the size of a football field, orbiting 370km (230 miles) above our heads, it would seem that the chances of a collision with a piece of space debris would be high.

Earlier this year, a meeting on space debris organised by the

"Spacesuits usually have about seven hours of oxygen, but that gets used up more quickly if you panic"



Space is getting crowded, as this illustration showing the number of satellites in orbit reveals

Inter-Agency Space Debris Coordination Committee (IADC), made up of representatives from space agencies around the world, concluded that the number of catastrophic collisions with spacecraft could soon increase to as many as one every five years. A catastrophic collision is one that results in the total breakup of the spacecraft the debris hits.

"A catastrophic collision involving the ISS is unlikely," says Dr Hugh Lewis, an aerospace engineer at the University of Southampton and the UK Space Agency's representative at the IADC space debris meeting. That's because the debris would need to be huge to impart enough energy to destroy something as large as the ISS.

Although the ISS is unlikely to be destroyed by space junk, if a debris collision did leave an astronaut stranded outside the ISS on a space walk, how long they could survive "depends on the resources of the suit", says Dr David Green of King's College London. Spacesuits usually have about seven hours of oxygen, but that gets used up more quickly if you panic – and not panicking would be a big ask for someone stranded in the blackness of space.

In *Gravity*, the stranded astronauts are wearing a version of NASA's Manned Maneuvering Unit used in 1984 Shuttle missions to zip around the outside of the spacecraft. But these days, astronauts on space walks wear a smaller propulsion system that is designed for emergencies and has enough propellant for only one 'self-rescue' of about 13 minutes.

EVASIVE MANOEUVRES

If space debris is spotted on a collision course with the ISS, there is something that can be done. So United States Strategic Command, part of the US Department of Defense, keeps a close eye on it. It tracks all debris larger than 10cm using radar. If anything looks like it's going to enter the area around the station, Strategic Command alerts flight controllers at NASA's Johnson Space Center in Houston, Texas.

If the piece of space debris has a greater than 1 in 100,000 chance of colliding with the station, Houston sends instructions to the ISS computers to alter its path. The ISS has a set of four gyroscopes and thrusters that allow it to change altitude, rotate and move side to side. Its typical speed during an avoidance manoeuvre is between 0.5 and 1m/s.

If something is spotted too late to make a move, the astronauts hunker down in the Soyuz escape craft and prepare to return to Earth if necessary. The last time that happened was in 2012 – luckily, the debris, a small fragment of the Russian Kosmos-2251 satellite, missed the ISS by over 10km (6 miles).

But chunks of metal hurtling through space are not the only threat to astronauts on space walks. Given how much they rely on equipment such as spacesuits while they are outside the Earth's protective atmosphere, malfunctions can spell big trouble.

A space walk in July this year had to be cut short when water started leaking into Italian astronaut Luca Parmitano's spacesuit helmet. "There is some in my eyes, and some in my nose. It's a lot of water," Parmitano said at the time. In space, this could be deadly. Floating water droplets could have caused Parmitano to drown. He was not hurt,

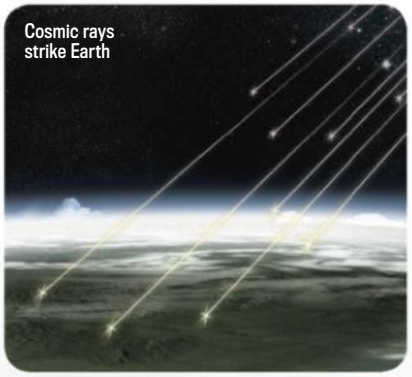
Sandra Bullock repairs the Hubble Space Telescope with George Clooney in *Gravity*

PHOTO: ESA, NASA X2, SCIENCE PHOTO LIBRARY, ALAMY, WARNER BROTHERS

THE THREE BIGGEST THREATS ABOARD THE ISS

It's not just about keeping calm...

Cosmonaut Sergei Krikalev takes part in fire training


Cosmic rays strike Earth


Even something as small as a nut could spell disaster for the ISS

FIRE

Space stations are confined spaces with a limited oxygen supply. As missions become longer in duration, rubbish – things like food packaging, disposable clothing and paper towels – will start to build up inside the spacecraft, increasing the risk of fire. A fire on the Mir space station started with the ignition of an oxygen canister, but other culprits could be overheating electronics or batteries.

RADIATION

On the International Space Station, astronauts are exposed to much higher levels of radiation than on Earth – up to 160 millisieverts for a six-month stay, compared to the two we receive per year on Earth. As we begin to undertake longer missions, radiation will become even more of a problem. "We'll be exposed to all kinds of cosmic radiation," says Dr David Green of King's College London.

SPACE DEBRIS

While a lot is done to mitigate the risk, even a tiny piece of debris can cause huge problems if it hits. A fleck of titanium oxide paint, travelling at 4km/s, hit Space Shuttle Challenger's windscreen in 1983 causing a chip. But though a piece of junk moving fast enough could destroy the ISS, it would be less of a problem on a trip to Mars, for instance, since we haven't begun littering further than low Earth orbit.

but NASA convened a 'Spacewalk Mishap Investigation Board' to look into what happened. Early indications suggest that water from the suit's coolant system might have been leaking out through its ventilation system.

In 2001 there was a different kind of leak. Ammonia from the Space Station's cooling system leaked out of a valve while two astronauts were on a space walk. As he struggled to close the valve, US astronaut Robert Curbeam's spacesuit and helmet accumulated a layer of toxic ammonia crystals an inch thick. His colleague had to brush off as much as he could, before Curbeam waited outside the Space Station for the rest to evaporate. When they returned inside, the crew wore oxygen masks while the life support system purged any remaining ammonia from the air.

Threats don't disappear once an astronaut is safely inside the station, either. Possibly the biggest danger is fire, which behaves differently in space. "In zero gravity, the hot gases don't go up anymore," says Professor José Torero, an expert in fire safety aboard spacecraft at the University of Queensland. "They become a semi-sphere and they get bigger and bigger, but they don't go anywhere."

In 1997, a fire broke out on the Mir space station after a cosmonaut routinely ignited a canister to add oxygen to the air supply. Because of the oxygen it contained, the canister acted like a blow torch. Eventually, the fire burnt out, but not before filling the station with smoke. "They were lucky that the flames didn't touch anything else," says Torero.


Greg Chamitoff enters an airlock on the ISS – he might have to do this in a hurry if an incoming piece of space junk is detected

Rather than trying to actively extinguish a fire, the trick is to make sure it runs out of fuel. These days, NASA rigorously tests all materials that go up to the Space Station. If something is flammable, astronauts know to treat it with care – their life may depend on it.

So while missions in space are now commonplace, the dangers have not subsided, and with the ever-growing threat of space junk, astronauts will need to be more vigilant than ever. ■

KELLY OAKES is a science journalist and the writer of 'Click here' on p26

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Adam Rutherford is the presenter of *Inside Science* on BBC Radio 4

7 SYNTHETIC BIOLOGY BREAKTHROUGHS THAT WILL CHANGE THE WORLD

From new cancer treatments to DNA-based computers, biological engineering is powering a technological revolution. **Adam Rutherford** counts down the most exciting developments

ALL LIFE SITS on one sprawling tree. And because all life has a common origin, it shares universal characteristics, not least its underlying language: DNA. From bacteria to blue whales, the alphabet, encryption and translation of DNA is identical. We've been breeding related organisms for 10,000 years, but in the 1970s we invented the technology to profoundly violate the species barrier, capitalising on the fact that DNA's coding is the same in all creation. Genetic engineering was born. In the last few years, it's evolved into a new industrial revolution, where remixing and redesigning nature is the norm, and cells are the forges of invention...

ILLUSTRATOR: MAGICTORCH

IMMUNITY TO COSMIC RADIATION

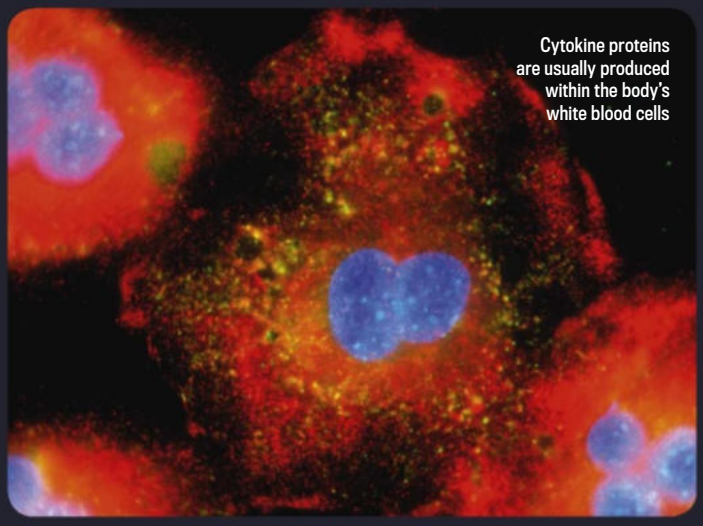
HOW NASA PLANS TO SHIELD ASTRONAUTS FROM HEALTH HAZARDS IN OUTER SPACE

NASA IS APPROACHING the final frontier when it comes to synthetic biology, with projects looking at how designed cells can help the exploration of strange new worlds. Based at Ames in Silicon Valley, one project aims to equip astronauts to endure the extreme hostility of space.

One of the biggest barriers to human exploration is that with current propulsion technology, trips will take years. That exposes astronauts to mutagenic and life-threatening levels of solar radiation and cosmic rays. Radiation slices up DNA, which can cause all sorts of problems, not least cancers.

But shielding is heavy, making it costly to launch off Earth.

At Ames, they are designing a synthetic biological circuit that will produce cytokines – the body's own defences against radiation damage – when it meets space radiation. But where do you put it? Having freefloating synthetic bacteria in your body is not a good idea. So NASA has designed a biocapsule out of carbon nanofibres whose pores are too small to let the bacteria escape, but big enough to let the cytokines they produce out. This capsule will be implanted underneath an astronaut's skin.

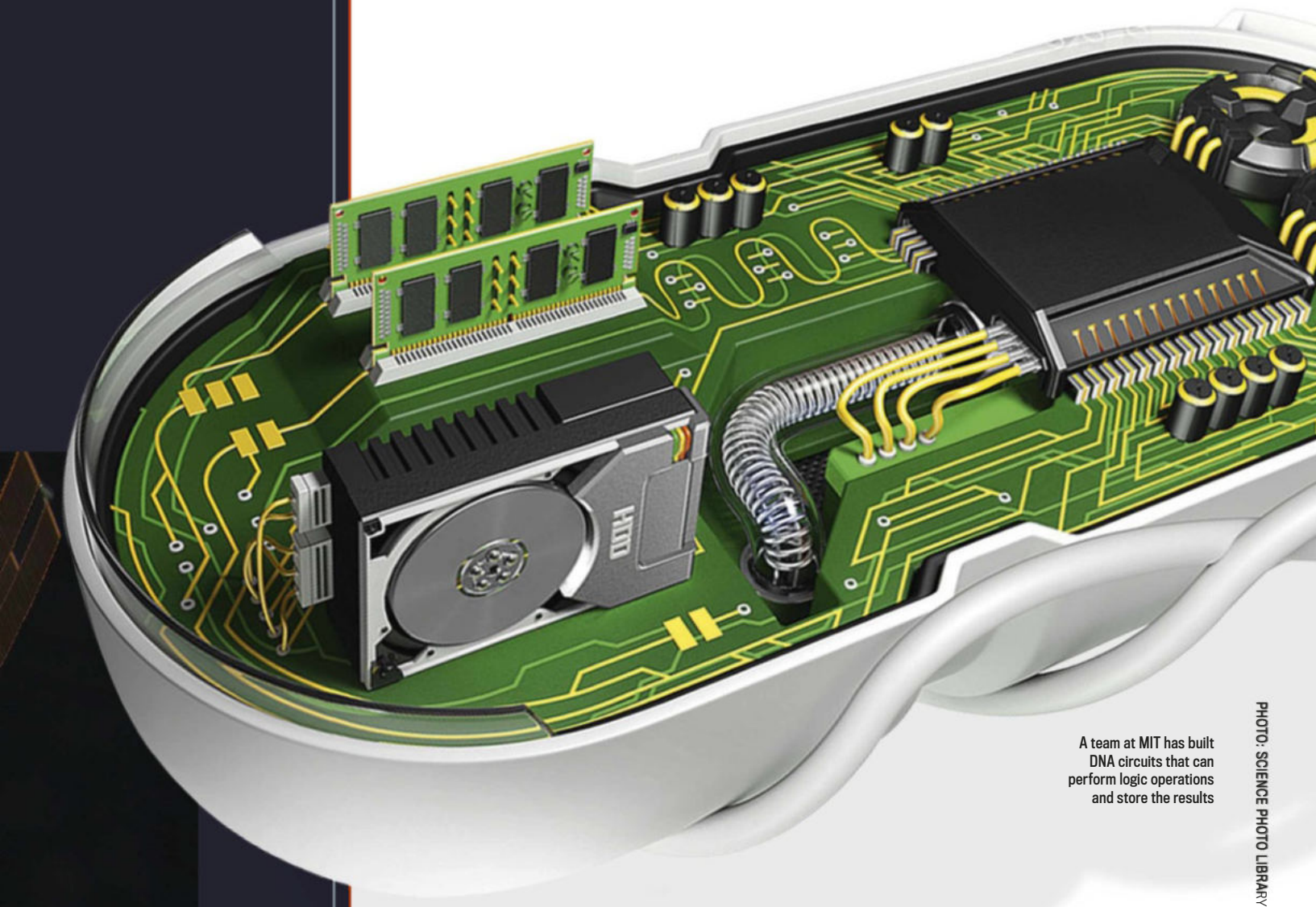


Cytokine proteins are usually produced within the body's white blood cells

The Alpha Magnetic Spectrometer on the ISS has taught us more about deadly cosmic rays

BIOLOGICAL COMPUTING

COMPUTING'S NEXT GREAT LEAP FORWARD COULD COME IN DNA FORM



A team at MIT has built DNA circuits that can perform logic operations and store the results

PHOTO: SCIENCE PHOTO LIBRARY X2. PIRO SIUTI/TIMOTHY LU ILLUSTRATOR: MAGICTORCH

SYNTHETIC BIOLOGY HAS taken its lead largely from electrical engineering. I write these words on a computer where millions of logic operations are happening almost instantaneously to produce a full stop as I hit this button. Lifeforms are much more complex than the most powerful computers, and noisier too, meaning that the underlying logic is not always linear, clean or obvious. Part of the work of the synthetic biology movement has been to strip out the noise of biological systems and reduce them to their component parts, ready for rebuilding.

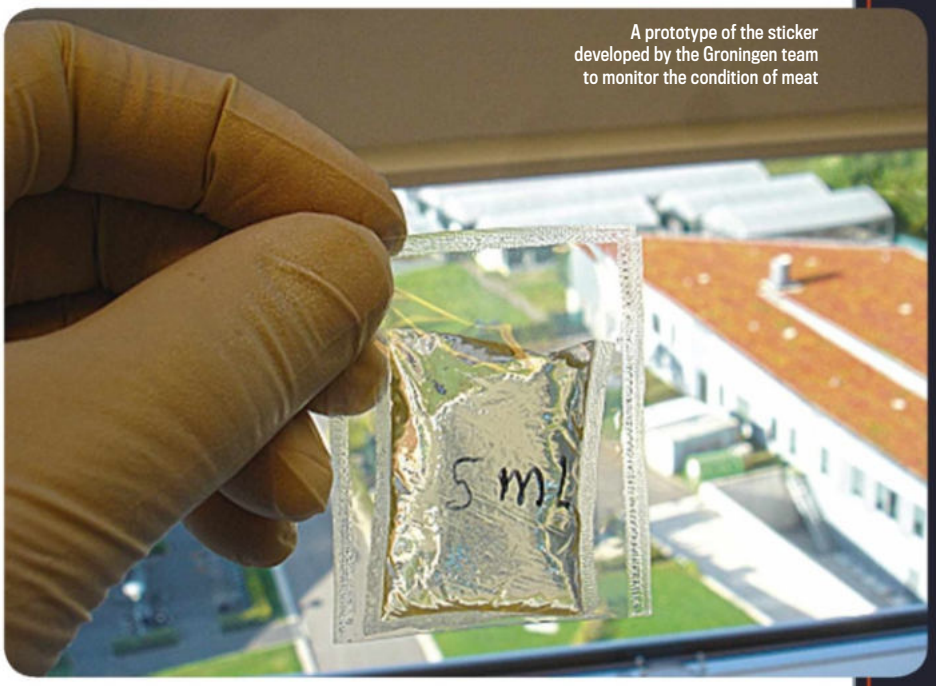
The result could be super-compact systems that can store information for tens of thousands of years. In 2013, we've seen a couple of high points in the computerisation of biological circuits. In February, Piro Siuti, John Yazbek and Timothy Lu from MIT programmed a circuit out of DNA that could store memory for up to 90 cell generations – roughly nine days – using logic functions akin to those in electronics. A month later, a team led by synthetic biology pioneer Drew Endy published a system of DNA that works like a transistor – the essential component behind all modern electronics. The transistor was arguably the enabling invention of the 20th Century; this biological version could pave a similar path.

CELLULAR TOOLSETS

SYNTHETIC BIOLOGISTS ARE GETTING THEIR OWN SET OF BUILDING BRICKS TO PLAY WITH

ANYONE WHO TRAVELS knows what a pain it is to have the right power adaptor. In electronics, parts were standardised decades ago, so that every time you needed a diode you didn't have to invent it. Genetic engineering has been slow to catch up, but now the BioBricks foundation is striving to make synthetic biology more productive and creative by making the parts fit together easily. Nowhere is the commodification of biology more apparent than in the International Genetically Engineered Machine (iGEM) competition. Each year, hundreds of undergraduates design a problem and a solution using only the parts available in the Registry of Standard Biological Parts – the shopping catalogue of synthetic biology. Each part is free, and in principle, standardised to fit together with the others, of which there are currently 10,000.

Some of the ideas are outlandish (see below), but the winner in 2012 was mundane and brilliantly practical. A team from the University of Groningen put together a bacterium that would change colour in the presence of rotting meat. Seal it safely in a plastic tray from the supermarket, and it'll tell you exactly how fresh it is.



A prototype of the sticker developed by the Groningen team to monitor the condition of meat

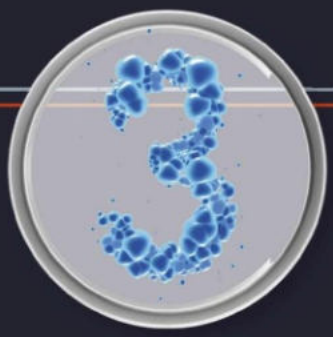
BACTERIAL OCEAN CLEANERS

COULD ENGINEERED MICROORGANISMS CLEAN UP THE OCEANS? WELL, NOT QUITE YET...

In 2012, a team from UCL proposed a method for cleaning up the oceans using genetically engineered bacteria

WHILE THE GRONINGEN team's winning effort could stop you getting food poisoning, the 2012 iGEM runners-up from University College London planned to clean up the oceans by assembling a plastic island. Everyone knows there are millions of tonnes of plastic rubbish floating in the oceans. It's not, as many think, a giant island of discarded bottles but, far more damagingly, billions of tiny fragments. These can accumulate in ocean gyres – area where currents meet, causing a vortex – and can enter the food chain, causing toxic or physical distress and death to animals.

UCL's team designed salt-tolerant, buoyant bacteria that would identify plastic fragments and either degrade them or aggregate them into lumps, which could be collected into an island they called, in James Bond villain style, the Plastic Republic. With safety in mind, the bugs were to be engineered to reduce environmental contamination, with a system that degraded their DNA if it were released. As with many iGEM projects, getting the bacteria to work within the competition's timeframe proved impossible. But the global scale and vision are typically ambitious.



CANCER ASSASSINS

GENETIC CIRCUITS COULD IDENTIFY AND ERADICATE CANCEROUS CELLS IN THE BODY

THE MOST EFFECTIVE ways we have of treating cancers are still chemotherapy and radiotherapy. Although these techniques are getting more and more precise in targeting the out-of-control malignant cells, they still kill many healthy cells, making the patient sick during their treatment.

Ron Weiss and his team at MIT have designed a genetic circuit that slots into a harmless virus, which then infects a cell. Once in there, it effectively asks the cell five biological questions. If the answer to any of these molecular queries is negative, the circuit deactivates. If all five answers are positive, the cell is identified as cancerous, with 100 per cent accuracy. When that happens, the next thing the circuit does is activate the cell's own suicide program. Compared to the blunderbuss approach of radiotherapy, this is a sniper.

Admittedly, this system only works in one type of cancer cell, called HeLa, and so far only in a culture, not yet in animal models. HeLa cells are among the most well-studied and well-characterised on Earth, and so the required level of targeting is not immediately scalable to the myriad other cancers and their ever-mutating genomes. But this is where progress begins.

HeLa cancer cells in a culture can be destroyed by a genetic circuit, but the technology doesn't currently work in live subjects

PHOTO: IGEM X2, SCIENCE PHOTO LIBRARY. EYEVINE ILLUSTRATOR: MAGICTORCH

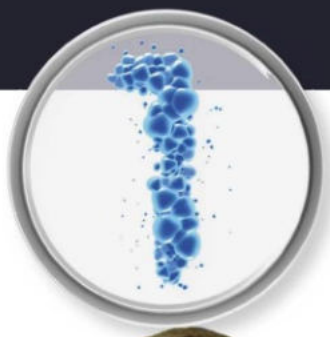
STREET-LIGHTING TREES

GLOWING FISH ARE ALREADY AVAILABLE IN PET SHOPS. ARE GLOWING TREES THE NEXT STEP?

WE'VE KNOWN ABOUT fluorescence in nature for decades. Osamu Shimomura, Martin Chalfie and Roger Tsien collected the Nobel Prize for Chemistry for discovering the Green Fluorescent Protein. Originally this gene encoded the jellyfish's underwater glow, but now it is used as the standard means of giving experimental transgenes a high-vis jacket. There's also luciferase, the protein that gives a firefly its eponymous trait. We've seen mice, cats, pigs and other species made to fluoresce in some way, for scientific purposes. And then there are GloFish, the first GM pets to go on sale in the US.

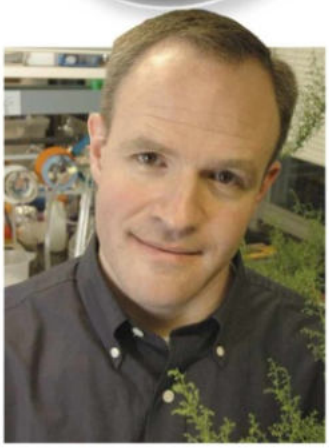
In June 2013 the first synthetic biology Kickstarter project raised nearly half a million dollars to make glowing plants. With a slick presentation video, a team of just three – led by Californian DNA hacker Antony Evans – exceeded its funding target by more than $400,000 in just a few weeks. Many speculated that this might be the pathway to fully sustainable electricity-free street lighting. Critics argue that the reality is a long way off, not least because trees are metabolically low-key, and the glow required to produce a decent light would be energetically demanding for the plant. But what this shows more than anything is that with the irresistible rise of synthetic biology, and the lowering of the entry bar to genetic engineering, such projects are no longer limited to traditional centres of research and development. Whether it works or not, the tech required to build previously unimaginable creations is now in the hands of the many. And they're asking you to back it.

Glowing plant pioneer Antony Evans (right) in the lab at his synthetic biology start-up Biocurious



ANTI-MALARIAL WEAPONS

CHEAPER, MORE EFFECTIVE MALARIA DRUGS COULD BE JUST AROUND THE CORNER



Jay Keasling has harnessed synthetic biology to create an anti-malarial drug

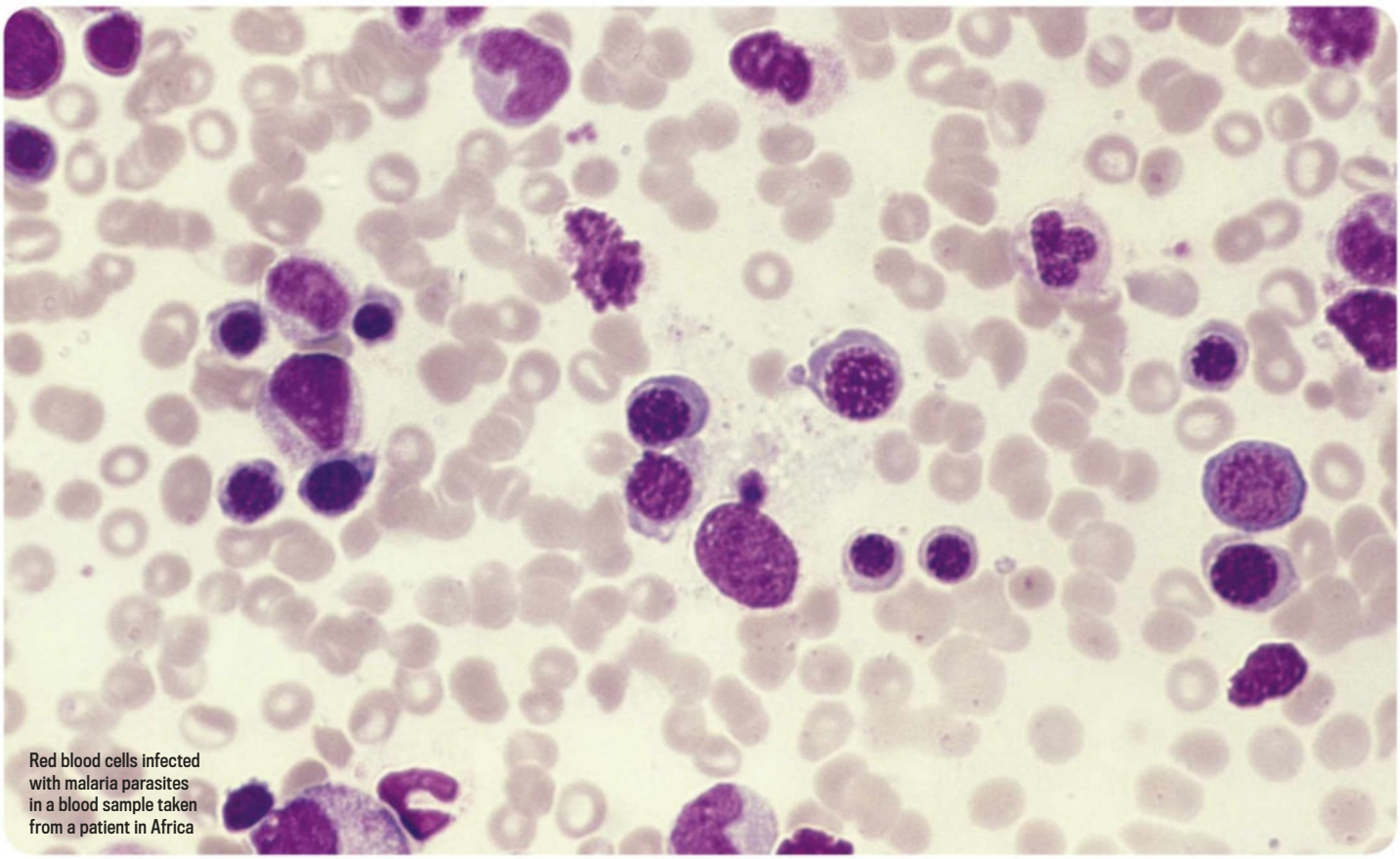
MALARIA HAS KILLED more humans than anything else in history. Up to a million people still die of the disease each year, and WHO estimates that the financial burden of treating malaria in sub-Saharan Africa since the 1960s has been hundreds of billions of dollars. Since the 17th Century, we've tackled it with a series of treatments such as quinine and chloroquine with limited success. The problem with this kind of serial medical monogamy is that the parasites evolve resistance. For that reason, the most effective treatment today is a cocktail of drugs, including the key ingredient artemisinin. It's an extract from a sweet wormwood, an Asian shrub that's been used in folk medicine for centuries. But wormwood is finicky to grow, and over the last few years the artemisinin market has been subject to boom and bust cycles, and hence fluctuating supply and costs.

Enter Jay Keasling (pictured). While trying to design a genetic circuit that would produce diesel in his labs at the University of California, Berkeley, one of his students noticed that a by-product was closely related to artemisinin, and they decided to follow this up. Built from 12 genes from three different organisms, the first successful cellular synthetic artemisinin producer was published in 2006. This year, after major investment from The Bill and Melinda Gates Foundation (and others), we will see distribution of this drug to malaria zones. The royalty-free licence was granted to French biotech company Sanofi-Aventis, and a promise made to not supply more than 50 per cent of the market, to offer some protection to traditional wormwood farmers.

The real-world delivery of such a drug will be the benchmark for the synthetic biology revolution. And that includes the practicalities of distribution. Already, we are seeing the emergence of artemisinin-resistant malaria in Cambodia and the Far East, probably as a result of black market trading and failure to comply with WHO's recommended combined therapies. Nevertheless, this story marks the first great product of synthetic biology. The revolution has begun. ■

WHAT DO YOU THINK?

Have we missed something? Or do you think the progress of genetic engineering should be slowed? Let us know at reply@sciencefocus.com



Red blood cells infected with malaria parasites in a blood sample taken from a patient in Africa

PHOTO: SCIENCE PHOTO LIBRARY, PEG SKORPINSKI/LAWRENCE BERKELY LABORATORY ILLUSTRATOR: MAGICTORCH

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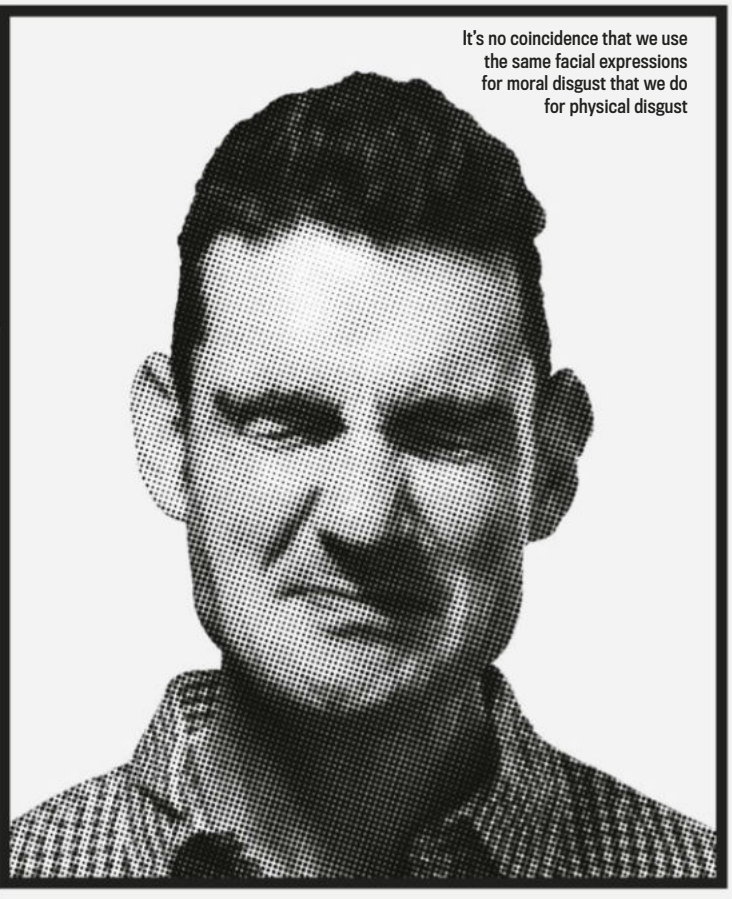
Daily Times
THURSDAY, 19 SEPTEMBER, 2013
PSYCHOLOGY
50p

WHY WE'RE DISGUSTED

Rotting food in the compost bin disgusts us. So do murderers and rapists – for reasons that are inextricably linked. Dr Valerie Curtis explains our innate fondness for moral outrage and why our very survival depends on it



It's no coincidence that we use the same facial expressions for moral disgust that we do for physical disgust

ALL OF US, whether we come from Kalamazoo or the Kalahari, Kyoto or Kensington feel disgust. And, with a few exceptions, we are all disgusted by pretty much the same things. Oozing wounds, mouldy food, maggots, cockroaches, poor hygiene, bodily emanations, skin eruptions, inappropriate sexual contact and violent crime all have the power to make our stomachs churn and our lips curl in the characteristic facial expression of disgust. It's as if we hear a voice in our heads saying: "Don't look! Don't touch!"

It's a powerful and hard to overcome feeling and there's a good reason why we react this way. Imagine, for a moment, a group of your ancient ancestors who had a mutation that took away their sense of disgust. Without it they might have found the idea of tasting poo attractive. Perhaps they would have been happy to eat food that was bad and perhaps they would have cuddled up to people with festering diseases. What would have happened to our

poor mutants? They would certainly have found it difficult to attract mates, and would have had trouble raising children successfully. So, as a result, they probably didn't have many descendants – which means that they would have been unlikely to be your ancestors.

In fact you (and I) must be descended from a long line of people with a fine sense of disgust. This is an emotion that evolved to do a simple but important job, to keep us away from the stinky, the wriggly, the filthy and the contaminated and so keep us safe from contracting life-threatening infections. Those warning bells we hear and those feelings of revulsion are like the voices of our ancestors telling us to turn away when we come into contact with anything that might harbour disease-causing organisms.

So if just about everything that people find disgusting can be traced back to the need to avoid infectious disease, why do people also report that they are disgusted by moral infractions? Our studies from around the world show that it's not just insects but injustice, not just cat poo but cruelty, not just rats but also racism that disgust. So is moral disgust actually disgust? Are they the same emotion or do we just use the language of disgust metaphorically, perhaps as a way of underlining our distaste for the immoral?

A number of studies suggest that moral and pathogen disgust may be one and the same thing. To start with both produce the same facial expression. At the University of Toronto Hanah Chapman wired up the faces of experimental subjects and then showed them images of faeces, gave them nasty things to taste and cheated them in a game. All three experiences produced the lip curl characteristic of disgust.

"Excuse me for saying so, but to me you are a walking bag of parasites"

The research conducted by the University of Toronto examined the link between expressions related to taste (above) and emotions (below) – the similarities between disgust (below left) and bitter (top right) are clear. The faces have had a green band placed over the upper lip and nose to accentuate the action of the levator labii superioris muscle that is used in facial expression

PHOTO: THINKSTOCK, SCIENCE PHOTO LIBRARY, SCIENCE/AAAS

Has someone you know been washing their hands more often than usual? It could be that they have recently committed an evil act and are now experiencing the 'Lady Macbeth effect'

Pathogen disgust also seems to influence your moral disgust. Simone Schnall and collaborators at the University of Plymouth subjected people to bad smells and nasty videos and then asked them to rate how they would punish immoral behaviour. Those who had experienced disgust were more severe in their moral judgements.

Following a similar logic, Chen-Bo Zhong's research at the University of Toronto reasoned that people who felt that they had done wrong might seek to purify themselves of disgusting matter. In a paper in the journal *Science* they reported what they called the 'Lady Macbeth effect': subjects who had been asked to recall an evil deed were then more likely to wash their hands at the end of the experiment.

Another way to figure out whether pathogen and moral disgust are the same is to look inside the brain. Several imaging studies have found some of the same regions, though not all of them, lit up by both visceral and moral disgust. So while we still can't be sure that moral and microbe disgust are the 'same' emotion, there is clearly some overlap.

THE EVOLUTION OF DISGUST

None of these studies clinch the issue completely. And none of them offer any explanation as to why we should have similar reactions in the face of filthy substances and filthy behaviour. However, there *is* a good reason for the overlap, and it's one we can find in our evolutionary past. We've seen how physical disgust wells up when we are faced with the things that might infect us, making us want to reject the object, push it away and have nothing more to do with it. Well, the objects that are most dangerous to us, in terms of infectious disease, are actually other people.

Excuse me for saying so, but to me you are a walking bag of parasites. One breath might give me influenza, one handshake might give me salmonella, one kiss might give me measles and more intimate contact with you might be even more disastrous. The most infectious – and therefore the most disgusting – things that I meet in my daily life are actually other people. Yet at the same time, I need social contact.

We humans are an intensely social species. We all get enormous benefits from being able to work together, to trade genes, foods, technologies and ideas. So there is a difficult trade-off calculation to be made. I need to get close to you to get the benefits of co-operating with you, but I need to stay away from you because you can pass me parasites. I have to mitigate the disease threat by learning a complicated dance that lets me get close, but not too close. I can share my books but not my toothbrush, my fresh food but not my leftovers, a kiss on the cheek but not in the armpit.

This is the essence of good manners: we all need to learn to behave in ways that avoid disgusting others (see 'The origin

WHEN DISGUST GOES WRONG

It may help us live in a cohesive society, but it can also destroy lives

LIKE ANY OF our organs, the disgust system can malfunction. Genes, wiring, chemistry, physiology and life experience can all conspire to make brains produce behaviour that is bad for us. High levels of disgust make some people so squeamish that they can't leave the house, eat or make social contact without fear of contamination. And people with low levels of disgust tend to cause offence through their lack of hygiene, and so end up socially excluded.

The best known disgust-related pathology is **Obsessive Compulsive Disorder (OCD)**. Thoughts of contamination and impurity intrude into daily life; to minimise their distress sufferers may constantly clean, sanitise and disinfect themselves and their environments. Other people, as the prime source of infectious pathogens, are also a major focus of overactive disgust. Sufferers from **social phobias** can't go out or tolerate proximity to others. Overactive disgust can ruin sex lives; indeed the first sign that a relationship may be in trouble is that a partner begins to feel disgust for the other's heretofore acceptable 'dirty' habits. **Post Traumatic Stress Disorder (PTSD)** is commonly thought of as resulting from fear-inducing experiences; however, intense disgust experiences, for example, encounters with grizzly items like rotting corpses have their own category of PTSD.

These pathologies of disgust can ruin lives, but they go under-diagnosed, partly because they are poorly understood.

Our hands are covered in bacteria – but don't think about it too much or you'll never leave the house

THE ORIGIN OF MANNERS

Without a strict code of conduct, we wouldn't be able to form groups and succeed as a species

WHAT DISTINGUISHES HUMANS from other animals? Lots of candidate evolutionary advances have been proposed: for example our use of tools, language, cooking, or our ability to imagine what others are thinking about. However, I have another candidate for what makes us uniquely human – manners. Without manners, and the disgust which is their foundation, the human way of life would be impossible.

Manners are seldom talked about in scientific discourse, yet they are ever-present in our daily behaviour. Parents invest huge effort in teaching good manners to their children and violations cause us to expend large amounts of emotional energy. Manners provide the scaffolding of operating rules for all our daily social interactions and, as such, deserve closer scrutiny.

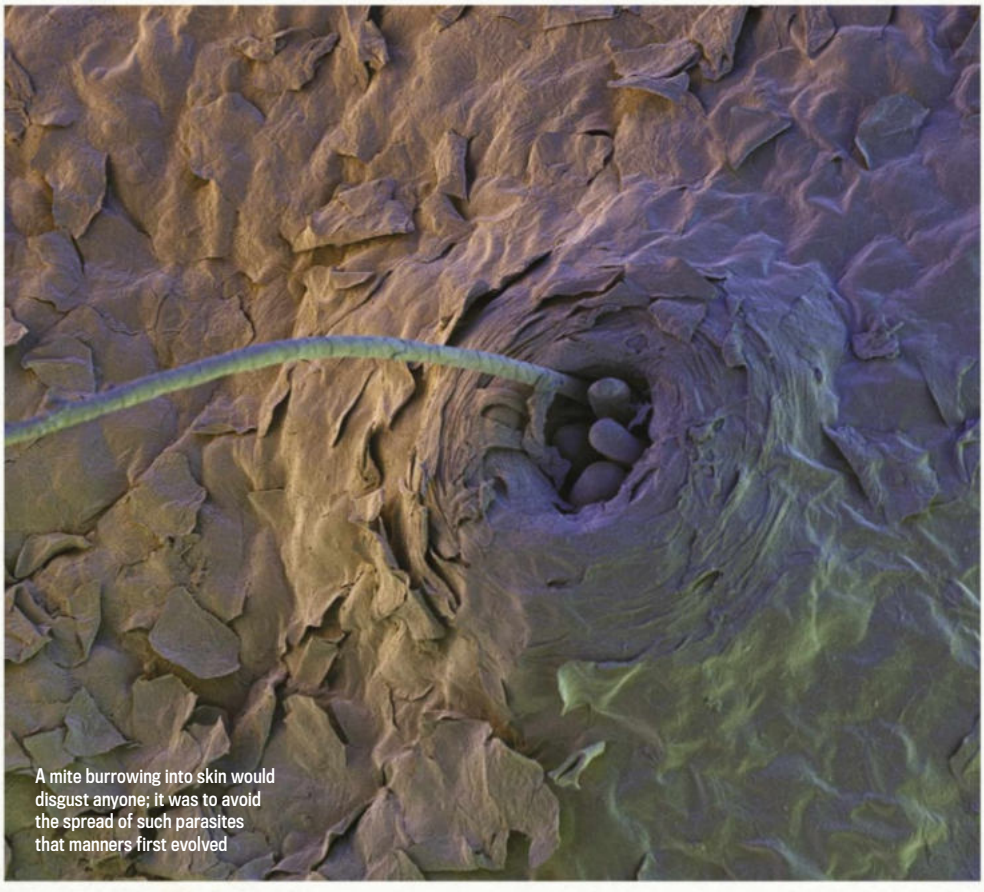
The oldest and most fundamental function of manners was to control disease. Ancient humans wanted to get the many benefits of being a social species. But there was a downside to cuddling up to others. To one human being, another human being is the most dangerous thing on the planet. That is because humans carry micro-organisms and parasites whose sole mission in life is to seek out and infect another human being.

This is why today all humans on the planet have rules about contact, bodily emanations and wastes. We all know the rules: how close it is polite to stand to others, where you can and cannot spit, where you can and cannot defecate, how you should be well groomed in public and who you can and can't share your towel or your toothbrush with.

These rules are more strongly enforced for strangers and are sometimes deliberately violated as a sign of trust. For example, shaking hands and kissing are signs that you wish to invest emotionally in someone, even at the risk of catching something infectious.

Once we had evolved the mental equipment for hygiene manners, it was a short step to extend this to the second sort of manners, which are the small courtesies that pave the way for social engagement. These include letting elders speak first, offering food to guests or disciplining children not to be greedy at mealtimes. Such behaviour signals respect and trust, without which we would be unable to move on to the bigger co-operative enterprises that characterise the human way of life.

A third and more ephemeral type of manners are those that we engage in to signal that we are insiders, that we are part of the group and so can be trusted. These include wearing the local style of clothing or following local custom – for example, in driving on the right side of the road.



A mite burrowing into skin would disgust anyone; it was to avoid the spread of such parasites that manners first evolved

PHOTO: GETTY X3, SCIENCE PHOTO LIBRARY

> "Disgust makes us push away and reject those that pose an infectious danger"

Generally speaking we've learnt to avoid contact with one another to prevent the spread of disease; shaking hands has emerged as a sign of trust precisely because it contravenes this general rule

of manners', left). And because this was such an important part of our lives as a social species we evolved new mental adaptations to help us learn to do this – the feeling of shame. A recent study by Roger Giner-Sorolla at Kent University showed that shame is the counterpart to disgust: it is the typical feeling elicited when one is exposed to someone showing you the facial expression of disgust. Who after all has not had the horrible experience of being called 'dirty' by a schoolmate or a teacher, and not then gone to great lengths never to be seen in a grubby shirt again?

Shame teaches us that if we want to be social we have to avoid being disgusting to others, to keep our emanations and waste products under control. And who has not in their past labelled someone as 'dirty'? Other people's dirt threatens us with parasites: the disgust that we consequently feel makes us want to reject and exclude that person from our society, to shame them so that the dirty shirt with its possible load of parasites never threatens us again in public.

SOCIALLY ACCEPTABLE

This, then, is the link between moral and organic disgust. An emotion that we use to punish folks that threaten us, or our group, with disease came to be used to punish people who threatened us in other ways. The murderer, the rapist, the cheat and the thief occasion disgust because it was adaptive to abhor such people, and to ostracise them as a threat to society. Disgust makes us push away those that pose an infectious danger to our bodies. Similarly it makes us want to reject and punish those who pose a physical danger to us. Shame helps us to learn how to avoid disgusting others with our lack of hygiene and so stay 'in' with the group. Similarly, shame teaches us not to behave immorally or we are likely to lose the benefits of living in a co-operative society.

Morality provides the set of operating rules that enable us to temporarily set aside our own interests for the sake of the greater benefits that can be accrued by working as a co-operative group. Moral disgust motivates us to punish and exclude those that cheat on their social obligations – people who are behaving as social parasites, much as disgust encourages us to punish and exclude those who cheat on their obligation not to spread disease. Without moral disgust our modern world, with all of its co-operative products such as cereals, fridges, nappies, books and the internet would not be possible. As we learn more about the scientific mechanisms of disgust, we'll learn more about what makes us tick and how we can help others. ■

If you want to be part of a group you'd better make sure you're not shamed by your personal hygiene

DR VALERIE CURTIS is Director of the Hygiene Centre at the London School of Hygiene and Tropical Medicine and the author of *Don't Look, Don't Touch: The Science Behind Revulsion*

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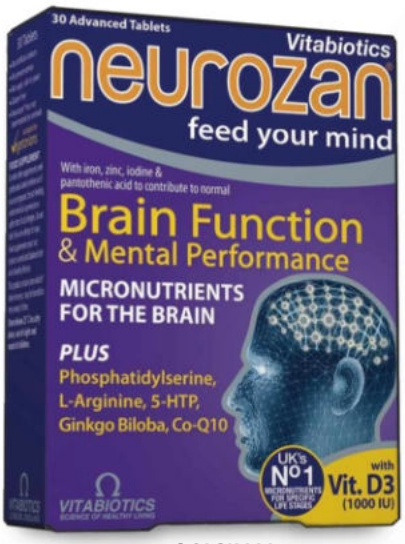
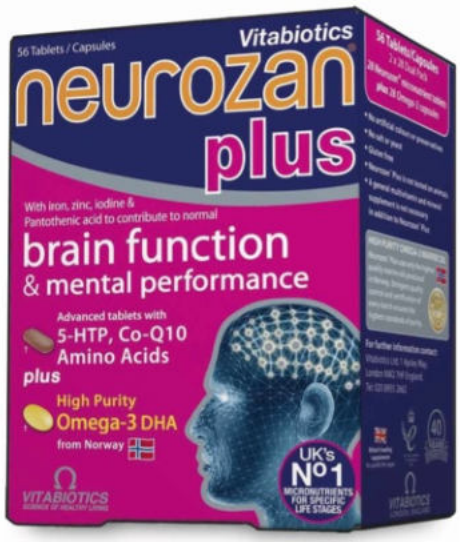


ORIGINAL



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Q&A YOUR QUESTIONS ANSWERED

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ROBERT MATTHEWS
After studying physics at Oxford, Robert became a science writer. He's a visiting reader in science at Aston University

GARETH MITCHELL
Starting out as a broadcast engineer, Gareth now writes and presents *Digital Planet* on the BBC World Service

LUIS VILLAZON
Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

EMAIL YOUR QUESTIONS TO questions@sciencefocus.com
or post to *Focus* Q&A, Tower House, Fairfax Street, Bristol, BS1 3BN

Q ADAM DOOLEY, MANCHESTER

Why are sonic booms so loud?

A SONIC BOOMS ARE the result of pressure waves that build up around objects moving so fast that the surrounding air doesn't have time to get out of the way. Supersonic jets create big shock waves, and as the loudness of any sound depends on the size of the pressure waves causing it, the result is a very loud boom. **RM**

A supersonic jet crashes through the sound barrier creating an ear splitting sonic boom

PHOTO: ALAMY

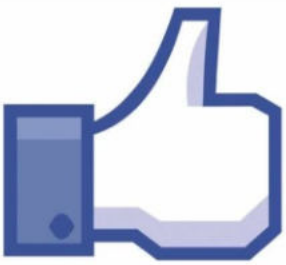
In Numbers

15 tonnes

was the weight of a 'fatberg' that was recently found blocking a London sewer. Consisting of congealed fat and other waste, the bus-sized lump has since been removed.

Q **RICHARD O'NEILL,** GLASGOW

Does social media prove the theory of six degrees of separation?



A IN 2011, Facebook found an average of just four degrees of separation amongst its then 720 million active users. With 69 billion friendships and a tenth of the world's population, it was quite a data set to draw on. Facebook found that 99.6 per cent of pairs of people were connected through six hops. And in 92 per cent of users, the number of links was just five, giving only four degrees of separation. **GM**

Q **KEITH GILMOUR,** GLASGOW

How are oil spills cleaned up?

A OVER THE YEARS everything from steam and chemical sprays to igniting the oil has been tried, with sometimes disastrous consequences. In 1967, the oil supertanker Torrey Canyon was holed off Land's End, triggering the world's first attempt at a major clean-up. Detergents were tried as a means of breaking up the oil slick, while aircraft attempted to burn it off by bombing it with napalm. It did not work well: a lot of marine life was either incinerated or poisoned by the chemicals.

In 1989 the Exxon Valdez disaster in Prince William Sound, Alaska saw the use of high-pressure steam cleaning of the affected area. This made the coastline look clean, but sent oil down into areas previously untouched, while scalding to death microscopic marine life.

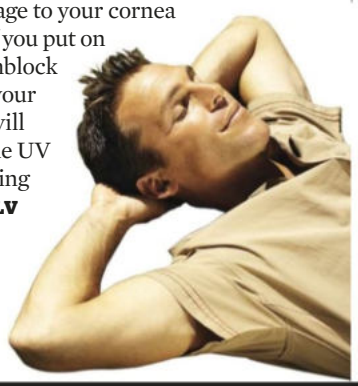
A host of techniques have been used in the aftermath of BP's Deepwater Horizon oil-rig disaster in the Gulf of Mexico in 2010, from the latest generation of dispersants to simply sucking the stuff up on to specially modified ships. But the same problems have emerged: studies suggest the dispersants are proving much more toxic than the method that may prove best in the long run: leaving nature to it. **RM**

A smaller ship attempts to off-load crude oil from the stricken Exxon Valdez in 1989

Q **JOHN CORFIELD,** DEVON

Does closing your eyelids protect eyes from UV?

A YOUR EYELIDS AREN'T entirely opaque to all the wavelengths of ultraviolet, but it's pretty close. Unprotected, your eyelids will get sunburn before you do much damage to your cornea or retina. If you put on enough sunblock to protect your eyelids, it will also stop the UV from reaching your eyes. **LV**



Your eyelids aren't a substitute for a pair of shades or suncream

Q **ROGER WEST**, SALISBURY

How do gorillas raised in captivity know what's safe to eat in the wild?

A BY INSTINCT. JUST as we evolved to enjoy the taste of certain foods and to find poisonous ones disgusting, so did gorillas. In the wild, mountain gorillas eat mostly leaves, shoots and stems; an adult male can chomp through more than 18kg (40lb) of vegetation in a day. Lowland gorillas eat mostly fruit, but this difference depends on what grows in these different environments.

In experiments in zoos, captive gorillas were given over 2000 pairs of foods to choose between. They showed remarkably consistent food choices, enjoying high sugar fruits and choosing a high ratio of sugar to fibre. They have even been tested using photographs of food. **SB**

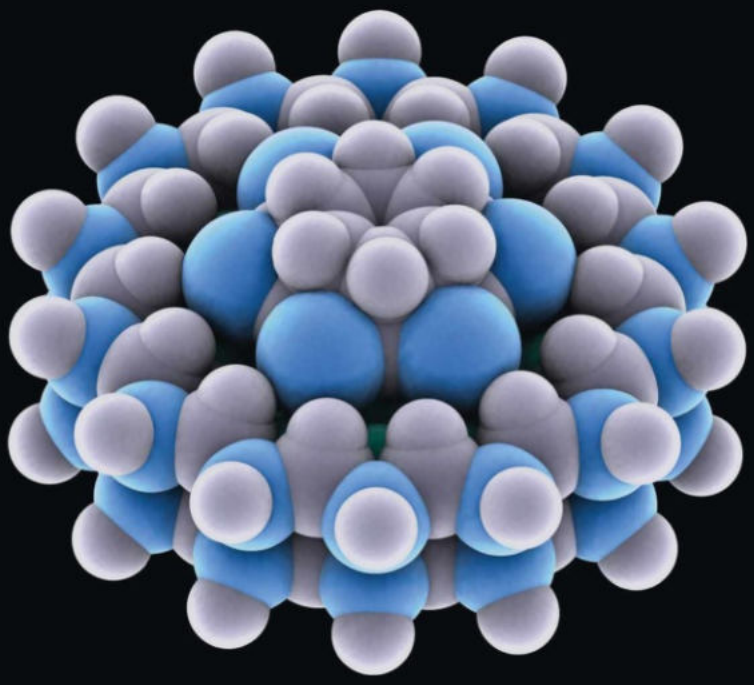
'Before I was released I had juicy fruit prepared for me – now I have to eat sticks again'

PHOTO: ALAMY, PRESS ASSOCIATION, SCIENCE PHOTO LIBRARY X2, FLPA, THINKSTOCK

WINNER!
Darren wins a copy of *Animal Earth* by Ross Piper (Thames & Hudson), worth £29.95

QUESTION OF THE MONTH

Atoms make up a nano-scale ball bearing – we probably won't be able to build things smaller than a single atom



DARREN GOODSEL, BOURNEMOUTH

Is there a limit to how small we can make things?

SCIENTISTS ARE GETTING adept at making atomic scale objects. In 1989, researchers at IBM made headlines by writing the company logo using individual xenon atoms dragged into place using a special electron microscope. By 2010 they had succeeded in drawing maps of the world so small that 1,000 of them could fit on a grain of sand. But such nanotechnological feats have their limits.

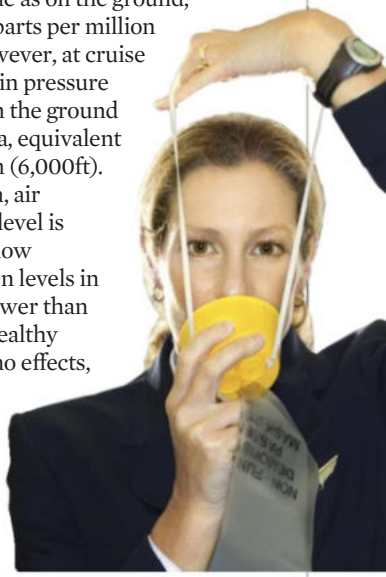
At the atomic scale, weird quantum phenomena emerge that can affect performance. One is the so-called Casimir Effect, a force that emerges literally from empty space to press surfaces together, causing nanomachines to jam up. And earlier this year, researchers in Germany found another limitation: the jiggling of electrons by the warmth of their surroundings, which generates magnetic fields affecting the abilities of electron microscopes.

But even if they overcome such issues, scientists know that the inherent fuzziness of the quantum world will prevent them making complex objects much smaller than an atom. **RM**

CLIVE FEINGOLD, CHESHIRE

What is the oxygen level in a plane?

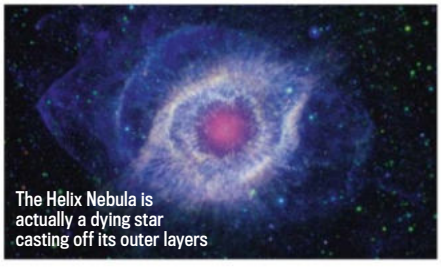
A OXYGEN LEVELS IN flight are broadly the same as on the ground, about 210,000 parts per million by volume. However, at cruise altitude the cabin pressure is lower than on the ground at around 82kPa, equivalent to about 1,800m (6,000ft). For comparison, air pressure at sea level is 101kPa. At this low pressure, oxygen levels in the blood are lower than at sea level. A healthy person suffers no effects, but those with respiratory illnesses sometimes need additional oxygen. **GM**



BRIAN PERKINS, BY EMAIL

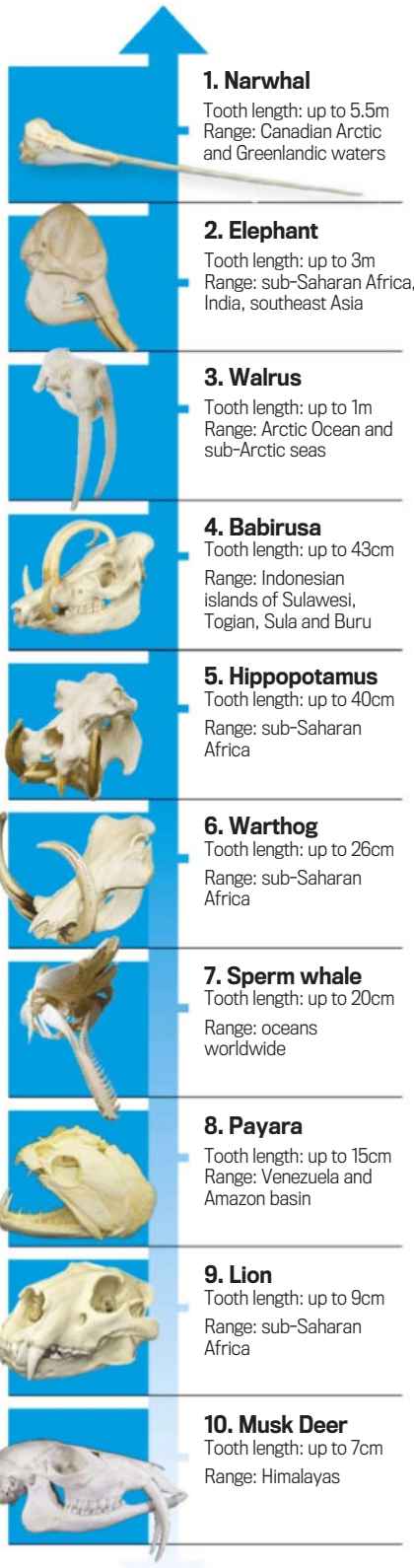
What is the minimum mass needed for a star to collapse?

A ALL STARS COLLAPSE under gravity once their nuclear fuel is expended. High mass stars do this explosively after the entire star collapses. Lower mass stars simply swell to a huge size as the core of the star shrinks to become a white dwarf. Even stars with extremely low mass will eventually collapse to become white dwarfs. However, they burn their fuel so slowly they are likely to outlive the age of the Universe before doing so. **AG**



The Helix Nebula is actually a dying star casting off its outer layers

TOP TEN
LONGEST ANIMAL TEETH



1. Narwhal
Tooth length: up to 5.5m
Range: Canadian Arctic and Greenlandic waters

2. Elephant
Tooth length: up to 3m
Range: sub-Saharan Africa, India, southeast Asia

3. Walrus
Tooth length: up to 1m
Range: Arctic Ocean and sub-Arctic seas

4. Babirusa
Tooth length: up to 43cm
Range: Indonesian islands of Sulawesi, Togian, Sula and Buru

5. Hippopotamus
Tooth length: up to 40cm
Range: sub-Saharan Africa

6. Warthog
Tooth length: up to 26cm
Range: sub-Saharan Africa

7. Sperm whale
Tooth length: up to 20cm
Range: oceans worldwide

8. Payara
Tooth length: up to 15cm
Range: Venezuela and Amazon basin

9. Lion
Tooth length: up to 9cm
Range: sub-Saharan Africa

10. Musk Deer
Tooth length: up to 7cm
Range: Himalayas

'Nevermind my fleas – what about your dandruff problem?'

Q **ANDREW EVERSETT,** DEVON

Can animals be allergic to humans?

YES THEY CAN. Little is known about allergies in wild animals, but some cats and dogs are known to react badly to their owners. The main culprit is dander, or dandruff; the bits of dead skin that fall from our scalps. Then there's all the dust around the house that contains varying amounts of dead skin. Dust mites thrive on these cells, dropping their tiny faeces into the mix, and providing even more causes of allergic reactions.

When cats are allergic they show symptoms much like asthma, including coughing, wheezing and shortness of breath. Dogs are more likely to suffer itching, sores and skin infections. The problem is getting worse now that so many animals are kept indoors, where they are constantly exposed to human allergens. Fresh air and time outdoors is the most natural remedy. **SB**

Q **BRIAN RAMSEY,** CAMBERLEY

Why do galaxies collide?

A GALAXIES COLLIDE BECAUSE of their mutual gravitational attraction. In general, galaxies are moving away from each other at an ever increasing rate, carried along by the expansion of the Universe. This is only noticeable over scales comparable to the size of galaxy clusters. The gravitational interaction between galaxies on these scales is insufficient to prevent them from moving apart. But on much smaller scales, the gravitational forces between galaxies can be large enough to overcome the cosmic expansion, allowing galaxies to interact, collide and sometimes merge.

In our own 'Local Group' of galaxies, for example, some galaxies are moving away from us and some toward us. The Andromeda Galaxy, our largest nearby companion, is currently heading toward the Milky Way at 402,336km/h and is due to hit us in 4 billion years. **AG**

Two galaxies known as the Antennae Galaxies are in the process of colliding

A can of cola contains around nine tea-spoons of sugar

Q **BERTIE GREEN,** LONDON

Which is better for you, cola or diet cola?

A THE MAIN DIFFERENCE is obviously that cola contains sugar and diet cola contains artificial sweetener. In the UK, that sweetener is aspartame and the current scientific consensus is that this additive is safe at the concentrations found in diet drinks. The 35g of sugar – around seven teaspoons – in a can of Coca-Cola, on the other hand, contains 139 calories, which will contribute to obesity and tooth decay. It can also lead to Type II diabetes if you drink too much of it. On balance, diet cola is probably the least bad but neither is actually good for you. **LV**

WHAT IS THIS?

KNOW THE ANSWER?
Go to **sciencefocus.com/qanda/what** and submit your answer now!

LAST MONTH'S ANSWER:
Well done to Ricky Cann, who correctly guessed a dendritic stem cell.

Q **JOHN LEWANDOWSKI,** HARTLEPOOL

Why is ice cream colder after you suck a mint?

Test your own cold receptors by giving yourself a brain freeze

A MINTS CONTAIN THE chemical menthol, which binds to the TRP-M8 receptors in your skin that sense cold. The temperature doesn't actually change; the menthol simply causes a false cold signal to be sent to your brain. If you add something like ice cream that actually is cold, this just increases the number of cold receptors that are firing at once.

This is similar to the reaction caused by chilli, which is caused by the chemical capsaicin and binds to the TRP-V1 receptors for heat. **LV**

Did you know?

The Blue Whale has the largest heart of any animal – it's roughly the size of a Volkswagen Beetle car!

Q **JOHN RADCLIFFE,** BLACKPOOL

What is the most powerful nuclear bomb ever detonated?

A ON 30 OCTOBER, 1961, the Soviet Union tested the AN602 thermonuclear bomb, nicknamed the 'Tsar Bomb', over Novaya Zemlya north of the Arctic Circle. The nuclear fusion-powered explosion was equivalent to over 50 million tonnes of TNT, over a 1,000 times more devastating than the atomic bombs dropped on Japan in 1945. **RM**

The annual Soviet fireworks display got a little out of hand

Q **GREG SMITH**, MANCHESTER

How much energy does it take to manufacture an average car?

A THIS IS A tricky thing to calculate. You can't just measure the electricity and gas bills of a car manufacturing plant and divide it by the number of cars made in that time. That wouldn't include the cost of mining and refining the materials used at the plant. But a detailed study by the US Department of Energy in 2010 came up with an average value of 34 gigajoules per car. That's the equivalent of 9,445kWh of electricity, or about 1.5 tonnes of coal. **LV**

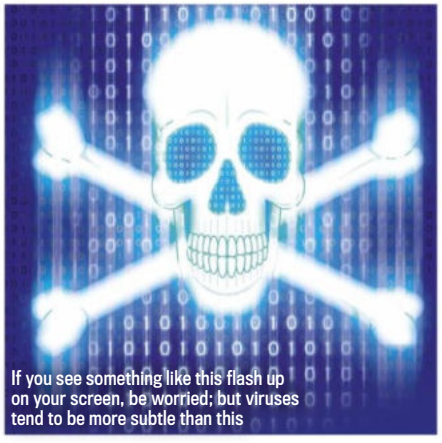
PATRICK FRIEND, ALTON

How do computer viruses work?

SOME VIRUSES ATTACK the computer's boot sector, the area on the hard drive that hosts the code for the start-up routine. Such a root code virus causes havoc because it runs itself every time you switch on the computer. Other viruses are hidden in emails, games or attached documents. These applications will appear to run normally but in the background; the malign code plays tricks like sending infected emails to everyone in your contacts list.

Another kind of malicious agent is the worm. This is able to replicate itself, often programming the infected machine to send copies to myriad random computers. Successful worms spread almost exponentially through networks, consuming processing power and bandwidth as they go.

But some of the most widespread disruption comes from botnets. Malicious code, often spread through email attachments, installs itself on thousands of computers. The hijacked machines act as an unwitting army of zombies firing off spam emails or blitzing targets like defence or corporate mainframes. They overwhelm them with a barrage of requests for information in so-called distributed denial of service attacks. **GM**



If you see something like this flash up on your screen, be worried; but viruses tend to be more subtle than this

In Numbers

1,223km/h

(760mph) is the speed of the Hyperloop, a new form of transport proposed by entrepreneur Elon Musk. It would fire passengers sitting in capsules down tubes and would take half an hour to go from San Francisco to LA.

SIMON SERVAL, DONCASTER

How do poisons differ between bees and wasps?

BOTH BEE AND wasp venom contain a painful cocktail of proteins, but the exact formulation varies from species to species. The most toxic component of bee venom is phospholipase, which destroys cell membranes and lowers blood pressure. It also contains melittin, which causes the most pain and amplifies the effect of the phospholipase.

Wasp venom is also made up of phospholipase, but it uses the neurotransmitter acetylcholine to amplify the pain. Although bee venom is acidic and wasp venom is mildly alkali, this is just incidental and doesn't play a big part in the level of pain of the sting itself. **LV**

There's no need to swat a bee after it's stung you – leaving its sting behind results in the insect's death

LORELY MASKELL, HIGH WYCOMBE

How did sexual reproduction evolve?

SEXUAL REPRODUCTION IS at least 1.2 billion years old, much older than the first appearance of multicellular life on Earth. When these early single-celled organisms reproduced, they simply duplicated their DNA (or RNA, which is a simpler, single-stranded version of DNA) and divided into two identical cells.

This was an efficient way of increasing in number but because the offspring were clones, it didn't do much to increase variety. Genes could mutate spontaneously over time, but there was no way to quickly bring useful combinations of genes together. Each cell strain had to wait for random mutation to supply all the genes of a particular combination in the same individual at once.

Sexual reproduction shortcuts this by allowing organisms to shuffle their genetic deck of cards. But it may have originally begun as cannibalism: one cell ate another but instead of digesting it completely, the prey DNA became incorporated into the predator cell. If certain genes improved the cellular machinery to make it easier to splice in new genetic sequences, they would be more likely to get carried over as cells ate each other. Eventually this could have evolved into the formation of specialised egg and sperm cells.

Alternatively sex could have begun as a sort of infection. Viruses work by injecting their DNA into a host cell and hijacking the cellular apparatus to make more copies of themselves. If some genes from the ancient host organisms got carried along by the virus when it moved to another host, this could have worked like a primitive form of sperm to share DNA. **LV**

Which came first? The sperm or the egg?

PHOTO: SCIENCE PHOTO LIBRARY X2, THINKSTOCK, STFC ILLUSTRATOR: PAUL WOTTON

HOW IT WORKS

NEXT-GENERATION FINGERPRINTING

EVERY TIME YOU touch your fingertip to a surface, you imprint it with a precise pattern of sweat and oil. The odds of this fingerprint matching another individual's are 1 in 64 billion. Research into a new way of visualising fingerprints on metal surfaces could dramatically increase their use as an identification tool in criminal investigations.

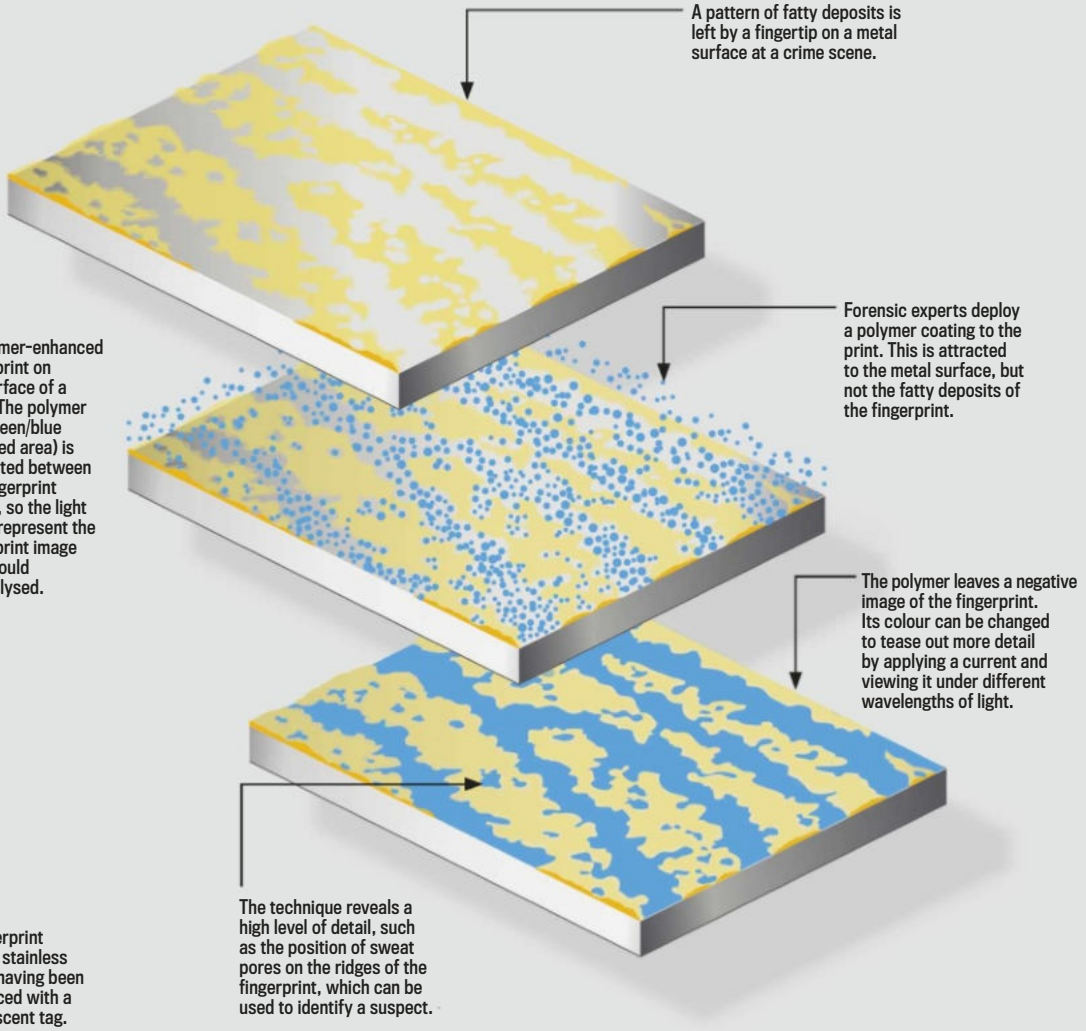
Conventionally, collecting fingerprint forensic evidence involves dusting a coloured powder over the sticky residues left behind on a surface. But the poor sensitivity of this technique means that only 10 per cent of prints can be used as evidence in court. Researchers from the University of Leicester, the ISIS research centre in Oxford and France's Institut Laue-Langevin are developing a more sensitive approach. Known as a fluorescent fingerprint tag, it will identify prints on metal, like a knife or a bullet. An electric current is passed through the metal surface, allowing an 'electro-active' film to be applied over it. Any fingerprint residues on the surface are electrically insulating, so they act as a stencil and block the film from being deposited. This creates a negative image of the print on the bare metal.

The film is also electrochromic, meaning that it changes colour when an electrical voltage is applied. The research team, led by Professor Robert Hillman, also incorporated fluorophores into the film, molecules that change colour when exposed to light or ultra-violet rays.

Using electricity and light, the colouration can be finely tuned to create the best possible contrast between the fingerprint and the background surface.

A polymer-enhanced fingerprint on the surface of a knife. The polymer (the green/blue coloured area) is deposited between the fingerprint ridges, so the light areas represent the fingerprint image that would be analysed.

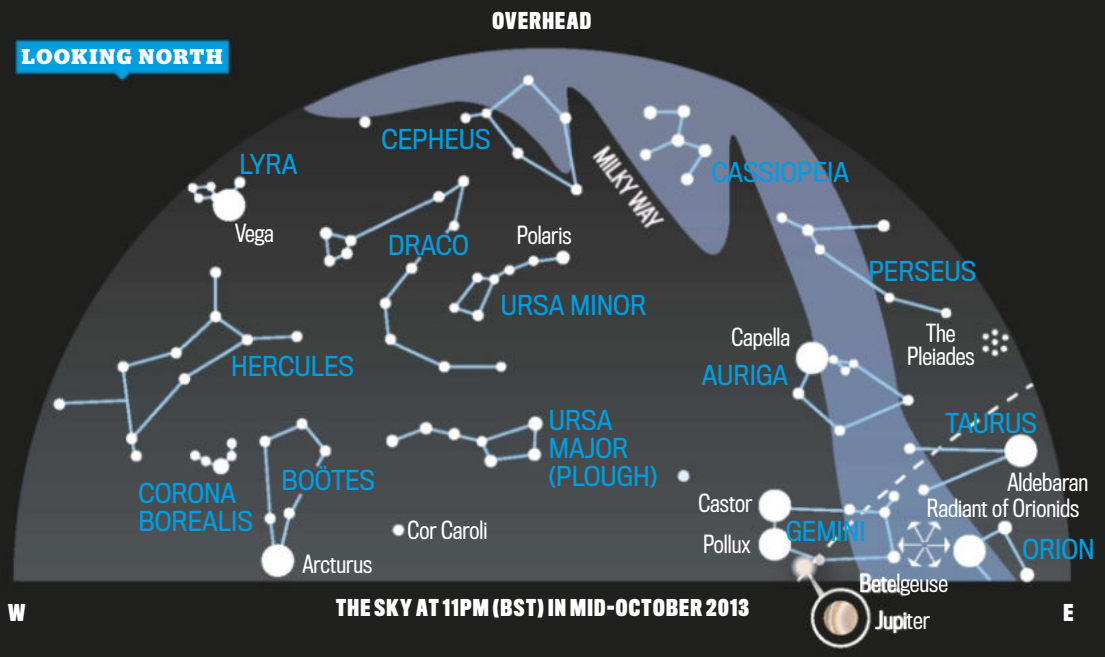
A fingerprint left on stainless steel, having been enhanced with a fluorescent tag.

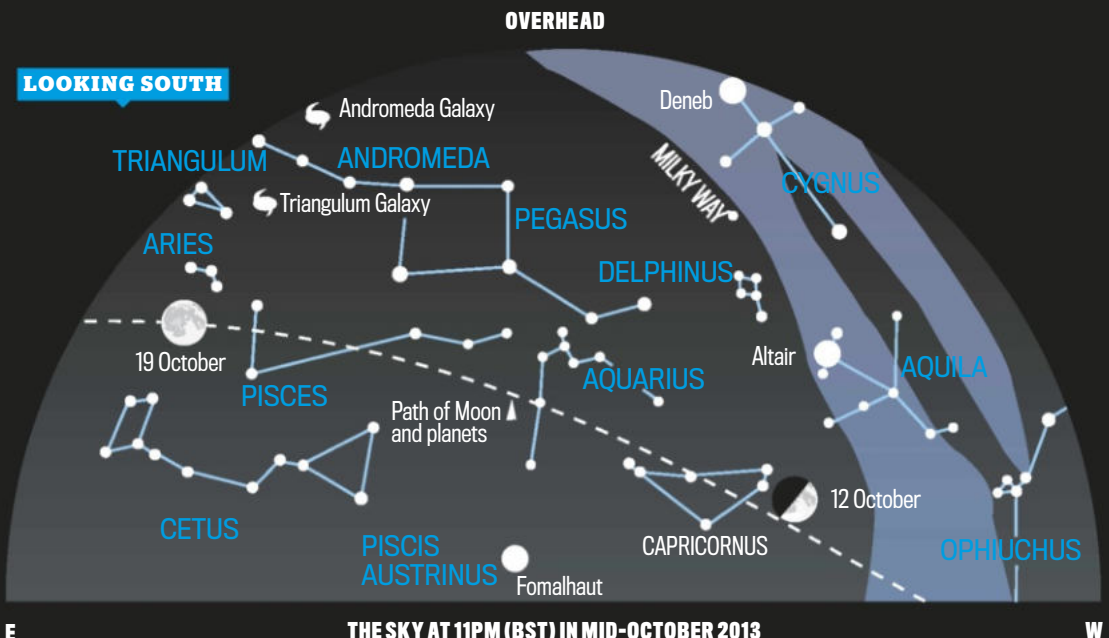


THE NIGHT SKY: WHAT CAN I SEE IN OCTOBER?

Astronomy with Heather Couper and Nigel Henbest

THERE'S NO BETTER time to get acquainted with the glories of the night sky than in October. You don't have to stay up too late for the sky to grow really dark – especially with British Summer Time ending on 27 October. We are treated to the sight of two fantastic planets – Venus and Jupiter – and a shower of shooting stars; plus the Milky Way stretching overhead.





LOOKING NORTH

All month, late evening
Brilliant Jupiter is rising northeast around 11pm. The giant planet lies next to the star Wasat in Gemini, and will be a major fixture in the sky for the next few months.

20/21 October, after midnight
Jupiter seems to be spitting out shooting stars tonight: in fact, these meteors rain down every October from a point in Gemini, and this year it's near Jupiter. These Geminid meteors are fragments from Halley's Comet burning up high in Earth's atmosphere.

LOOKING SOUTH

All month, late evening,
Leap on-board a time machine this month! When you have a really dark clear night, look high in the southeast to spot the faint smudge of the Andromeda Galaxy. You are seeing it not as it is now, but as it was two million years ago! That's how long light has taken to travel the immense distance from Andromeda to your eye.

8 October, 7.30pm
The crescent Moon is teaming up with the Evening Star (Venus), low in the twilight to the southwest.

Find out more

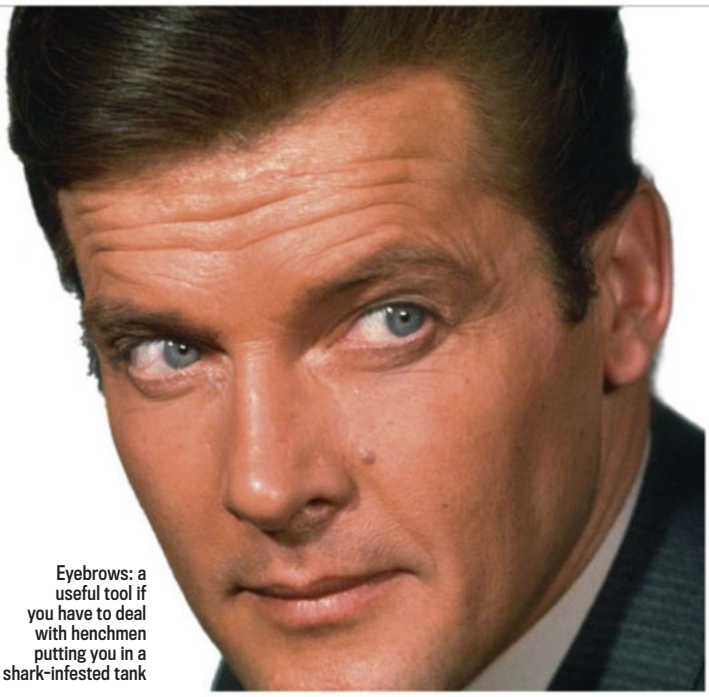
Stargazing 2013
Discover astronomy with Heather Couper and Nigel Henbest (Philip's, £6.99)

GUINEVERE LEAH, MELBOURNE, AUSTRALIA

Why do we have eyebrows?

ORIGINALLY TO KEEP rain and sweat out of our eyes. As a species we humans rely on our sight more than any other sense, and water can seriously blur vision. Eyebrows may also deflect debris and shield our eyes from the Sun. So while we slowly evolved to lose most of our body hair, our eyelashes and eyebrows remained.

But eyebrows then took on another function: communication. Facial expressions convey meaning and emotions in ways that are hard to fake, and the eyebrows exaggerate expressions. Even in cartoons, a simple line above the eyes is enough to denote anger, fear, or surprise in a face, and experiments have shown that we can recognise a familiar face more easily when the eyes are blanked out than when the eyebrows are. So if you're tempted to redesign your eyebrows by shaving or plucking them, do remember their many uses. **SB**



Eyebrows: a useful tool if you have to deal with henchmen putting you in a shark-infested tank

You might want to have your bike's brakes checked regularly if you live at the top of Baldwin Street, New Zealand

NAOMI CHAMBERS, CHELMSFORD

What is the maximum gradient a cyclist could climb?

WITH ENOUGH RUN-up, you can ride up any gradient of hill, including completely vertical. But beginning from a standing start, the limiting factor is the power you can supply from your legs. Most cyclists can't balance once they are travelling at less than 1m/s. An Olympic athlete can put out about 370–400 watts of power for short periods and this would theoretically let them climb at 1m/s up a roughly 45 per cent grade hill, ignoring friction from the bike axles.

There aren't any roads with hills that steep, but one of the steepest in the world is Baldwin Street in New Zealand. This has a maximum grade of about 35 per cent and there are videos on YouTube of cyclists making it to the top. They invariably zig-zag on the way up though, which flattens the effective gradient. **LV**

PHOTO: ALAMY, GETTY

SALLY MUSKELL, LITTLEHAMPTON

Why do earthworms surface after rain?

A worm wriggling around in wet weather could be thinking that it's escaped the clutches of a mole

A NOT BECAUSE THEY might drown. People often claim that this is the explanation, yet earthworms breathe by exchanging oxygen and carbon dioxide through their skin, which they keep wet with a slimy mucus. This means they are happiest in damp soil and most species can survive for several days under water. So a brief rainstorm should not bother them. Indeed, they may even exploit the wet weather to travel longer distances than they would normally be able to underground.

Some may need to come to the surface to mate when it is wet enough, but only a very few of the 4,400 known species of earthworms do this. Another possibility is that earthworms confuse the sound of rain with a predator, such as a mole, and so make their way upwards to the surface to escape. Certainly the animals are well known to respond to such sounds, as any worm catcher will tell you. Some old tricks include vibrating sticks, saws on wooden stakes. And, more bizarrely, giving worms tea and beer. **SB**

HARRIET MORRIS, ISLE OF MAN

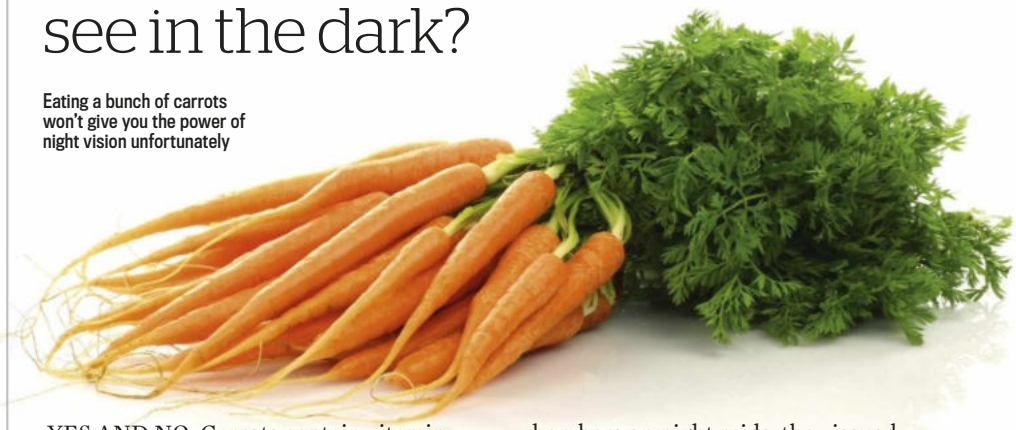
Why does skin stick to frosted metal?

A IF YOU PUT your tongue on a frozen metal flagpole, the high conductivity of the metal removes heat from your tongue much faster than your body can supply it. This makes the water in your saliva freeze into ice very quickly. The ice creates hydrogen bonds between the metal and your skin, just like liquid water does, except that now the whole surface bonds together to resist the force as you pull away. The same thing will happen with your fingers because your fingerprints provide some roughness and your skin also usually has a tiny amount of moisture from sweat. But very smooth, very dry skin won't stick. **LV**

It won't taste of anything and you could be in for a painful separation

ALAN HUGHES-HALLETT, WANSTROW

Do carrots really help you see in the dark?



Eating a bunch of carrots won't give you the power of night vision unfortunately

YES AND NO. Carrots contain vitamin A, or retinol, and this is required for your body to synthesise rhodopsin, which is the pigment in your eyes that operates in low-light conditions. If you have a vitamin A deficiency, you will develop nyctalopia or night blindness. Eating carrots would correct this and improve your night vision, but only to the point of an ordinary healthy person – it won't ever let you see in complete darkness.

The idea that it might is due to a myth begun by the Air Ministry in World War II. To prevent the Germans finding out that Britain was using radar to intercept bombers on night raids, they issued press releases stating that British pilots were eating lots of carrots to give them exceptional night vision. This fooled the British public, as well as German High Command and an old wive's tale was born. **LV**

NEXT MONTH Over 20 more of your questions answered

For even more answers to the most puzzling questions, see the Q&A archive at **www.sciencefocus.com/qanda**

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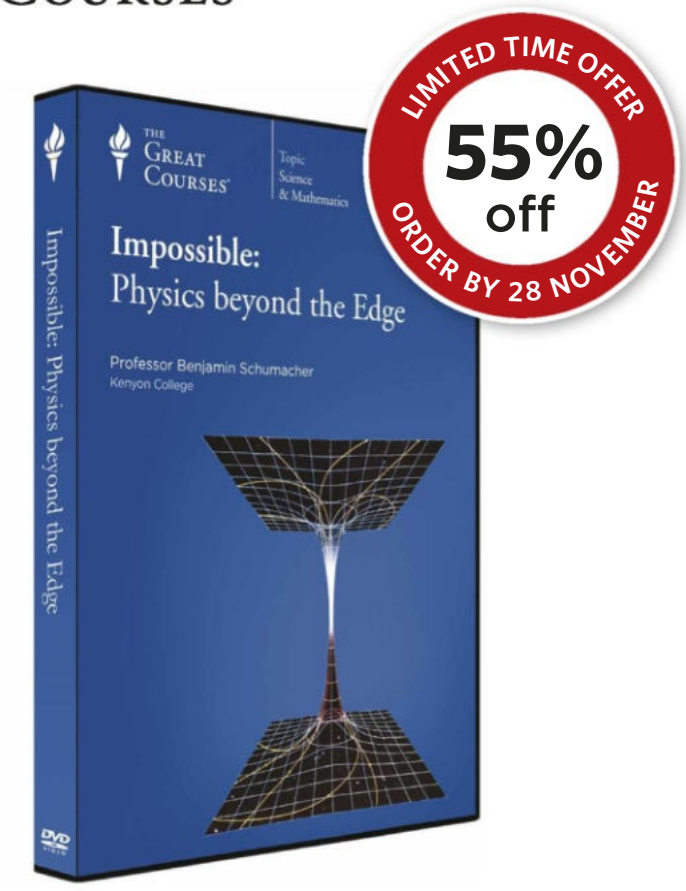

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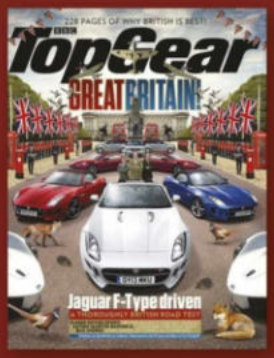

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THE FUTURE OF GADGETS

TECHHUB

EDITED BY **DANIEL BENNETT**

THIS MONTH

ON THE HORIZON

FOC.US

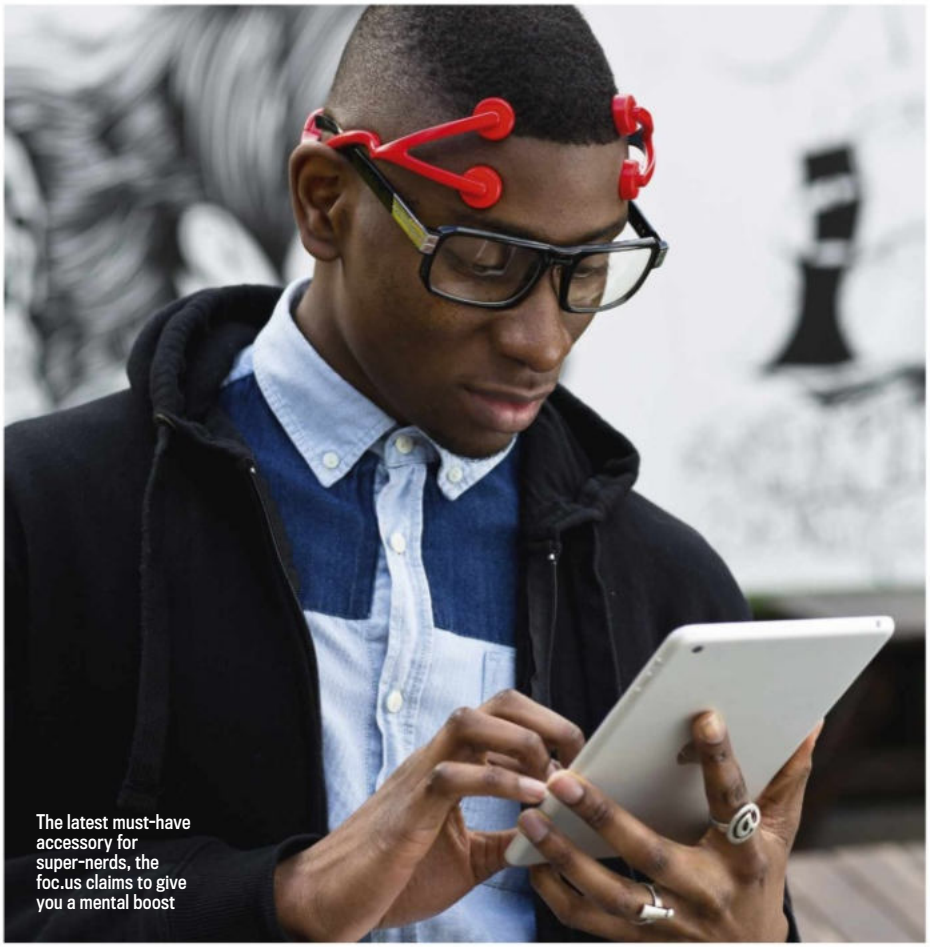
WWW.FOC.US, $249 (£160 PLUS P&P)

WORDS: DR BRADLEY VOYTEK

FOR CENTURIES people have sought quick fixes and miracle cures to enhance our vitality and make us faster, stronger, smarter, younger. Historically speaking, many of these 'fixes' have been pharmacological. Freud used cocaine to improve his mood and treat his patients while Queen Victoria was known to enjoy a wine infused with the drug. In fact it's only relatively recently – the late 1960s – that the sale of amphetamines was made illegal.

Now it seems the next form of mental stimulant could come in the shape of a piece of technology, and not a drug. Looking like something *Star Trek*'s Borg might wear, the foc.us device promises to 'make your synapses fire faster' with the application of a small electrical current to the brain for 30 minutes. The promised result is that you'll have sharpened reflexes and faster reactions. As a gamer, I can see the attraction. Those extra split seconds can make all the difference. It's certainly a shrewd business decision too: video games were a £43 billion ($67 billion) dollar industry in 2012, and professional gaming draws in sponsorship and viewing figures that rival physical sports. The company's bold claims may draw in others looking for a mental boost, and not just people who like to play video games.

Unfortunately as a scientist I'm sceptical. The technique being used by the foc.us headset is known as transcranial direct current stimulation



The latest must-have accessory for super-nerds, the foc.us claims to give you a mental boost

(tDCS). In the scientific world, studies using it have actually been quite promising. In carefully controlled experiments, low-level electrical excitation of *just the right* brain regions have provided a small boost to task performance. After a quick zap, volunteers have gotten slightly better at noticing if a square changed colour (after an hour of watching flashing coloured squares). But could this really extend to a task as complex as playing a video game?

The general idea is that if a certain brain region is involved in cognition – attention for example – then stimulating that area with an electrical pulse (priming it) should improve your ability to attend to what's happening around you. We also know that when you're engaged in a complex cognitive task (like playing *Call Of Duty: Modern Warfare*), certain neurones in specific brain areas fire more quickly.

So, I imagine the thinking at foc.us is that if we can speed up the rate of neuronal firing we should be able to enhance gaming ability. Unfortunately, that's a little like saying, "I can boost my computer's memory by jolting its hard drive with a battery!" – your IT department won't be happy.

Yes, sometimes tDCS provides a cognitive benefit; the data is indisputable. I myself make use of this technology in my lab. But its capabilities are too non-specific. In the brain, it matters *which* neurones are excited; alcohol excites a lot of neurones, but no one would claim that drinking four pints sharpens your reflexes.

And while stimulation methods have been proven to be safe for use in controlled experimental situations over the short-term, we don't know about long–term effects. We've been down this road before. Over the short term the data was very clear: cocaine and amphetamines were very effective at enhancing energy and mood, but we didn't know about long-term negative consequences. I will never say that we shouldn't test new drugs or new technology, but when companies promise to 'excite your prefrontal cortex' to give you 'the edge in online gaming' and 'let the force of electricity excite your neurones into firing faster', well... buyer beware.

DR BRADLEY VOYTEK is a neuroscientist at the University of California, San Diego

TECHOMETER

WHAT'S HOT

300TB OPTICAL DISCS

Sony and Panasonic are drawing up plans for a new disc format that would replace Blu-ray. These new optical discs would hold 300GB of data, just enough space for a single, 4K resolution (Ultra HD) film. This format would be four times sharper than the 1080p resolution Blu-ray offers. Televisions with 4K displays are already on sale, so alternative ways of getting Ultra HD content could spring up in the meantime.

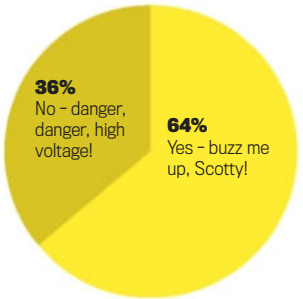
WHAT'S NOT

BLUETOOTH TOILETS

Bringing a whole new meaning to the term 'backdoor vulnerability', a Bluetooth toilet, which can be controlled via a smartphone, has been hacked. All of its functions, including the flush, bidet and hot-air blower, can be hijacked. The toilet, which even keeps a log (no pun intended) of your bowl movements, is stuck with the Bluetooth pin 0000, making it an easy target.

READER POLL

Would you sharpen your reflexes by stimulating your brain with electricity?



ILLUSTRATOR: LAUREN GENTRY

EARLY ADOPTER

BILL THOMPSON

Road to the future

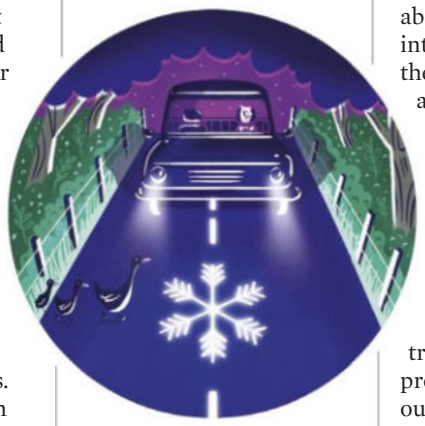
The Yorkshire Dales is a magical place, and I've spent more time than I'd like driving up and down the A1. When you travel up the ancient North Road, it's apparent how little roads have changed in comparison to everything else.

One person who agrees is Daan Roosegaarde, who runs the social design lab Studio Roosegaarde. He has developed a photoluminescent paint that can be used on road surfaces, for example for road markings. During the day the lines absorb sunlight and then glow for 10 hours to provide guidance to night drivers. This will save money and could also improve safety by making it affordable to illuminate country roads.

He also has paint with a temperature-sensitive ingredient that glows phosphorescent white when the temperature drops below zero. Roosegaarde proposes to use it to paint giant snowflakes on the road that will appear in frosty weather to warn drivers of icy conditions, instead of relying on in-car systems.

It's a lovely concept and later this year Heijmans, a Dutch road-building company, will build a 150m demonstration road with glowing green markings replacing street lights.

The next step is to make the road more 'aware' by equipping it with sensors for all sorts of things, like temperature, water and of course vehicle speed. The data collected can then be used to warn drivers, either through on-board information systems or by using it to guide self-driving cars like Google's.



The first UK self-driving car trial will take place in Oxford this year, and the move to autonomous vehicles seems unstoppable.

Imagine the end point and we have road systems designed from the ground up with intelligent materials and embedded computers. They will be efficient, low-power and safe because the whole system is managed by 'road service providers', the transport equivalent of internet service providers.

Something akin to this is already being built in South Korea. A new city called New Songdo will have its roads managed by Cisco, which will use real-time information like the current weather to optimise the city's traffic lights.

A system like this would make it a lot easier to get to Swaledale in Yorkshire each week, but for all my excitement one thing worries me. I'm uneasy about building an intelligent road system for the same reasons I am about turning the internet from a series of relatively 'dumb' pipes into a fully managed network. Once you do that you put enormous power in the hands of those in charge.

Just as we have to trust internet service providers not to feed all our data to GCHQ and to be fair in allocating bandwidth so that BBC iPlayer works properly, so we'd have to trust the road service providers not to send us on long detours so their higher-paying customers could drive at high speeds down empty roads as if they were in a car advert. The road to the future might not be so clear after all.

Bill Thompson contributes to news.bbc.co.uk and the BBC World Service

TELL US WHAT YOU THINK!
Do you want a highly managed smart road network with driverless cars? Give us your opinion by emailing **reply@sciencefocus.com**

COMING SOON

3 MONTHS

MOTO X

Motorola has launched its first new smartphone since it was acquired by Google. The Moto X is 'always listening' for voice commands from the user. Saying 'Okay Google Now...' tells the phone that you're about to issue instructions. *Motorola.com*

+ iPhone 5C
All the signs point towards a budget iPhone, available in several colours, going on sale before the year's out. *apple.com*

+ PS4
With video calling and social networks loaded as standard, Sony's next PlayStation is set to provide a more social gaming experience. *playstation.com*

6 MONTHS

NEXUS Q

Google's attempt at a TV set-top box flopped initially, but the search giant is thought to be readying a follow-up with more services, including cloud gaming. *Google.co.uk/nexus*

+ LG Smartwatch
Following the launch of its new G2 smartphone, LG registered the G Watch brand. It's fuelled rumours that the company will launch an Android-powered smartwatch before the year's out. *Lg.com*

+ Mercedes S-Class
The car that sets the standard for the rest of the motoring industry comes with 'Distronic Plus Steering Assistance'. In other words, autonomous motorway driving. *Mercedes.com*

9 MONTHS

SAMSUNG SMARTWATCH

The South Korean tech company has penned a patent for an Android-powered watch with a bendable screen that wraps around the wearer's wrist. *Samsung.com*

+ Oculus Rift
The virtual reality headset could change entertainment as we know it. NASA has already developed virtual tours of Mars and the ISS using the hardware. *Oculusvr.com*

+ Samsung Youm
As well as a bendable watch, Samsung is readying a flexible phone. With the battery packed into a lipstick-sized cylinder the rest of the phone can be rolled up. *Samsung.com*

JUST LANDED

MAGNIFICENT GESTURE

The film *Minority Report* envisaged a future of interactive 3D displays. Jamie Carter gets hands-on with Leap Motion, which turns science fiction into reality

WE CAN TOUCH, tap and even talk to our devices, so the arrival of gesture control for computers shouldn't come as a shock. Leap Motion creates a 3D motion control area in front of your computer by using a small USB stick-like device that sits in front of your keyboard. It uses a combination of cameras and infrared LEDs to capture movement.

But where the other gesture-control device, Microsoft's Xbox Kinect, follows your whole body, the Leap Motion only tracks your hands. During the set-up procedure the software showed a 3D version of my hand on the screen. When I moved just one fingertip very slightly, the 3D model hand moved in unison.

However, although it runs on both Windows and Mac computers, the Leap Motion software works only within its own dedicated apps; you're not going to be checking your email or surfing the web. There are over 70 apps, from the 3D dissection of skeletons on Cyber Science Motion to a *New York Times* app, though most are simple games like *Cut The Rope*. The main problem is that there is no common Leap language, no gesture that consistently works. We were addicted to *Cut The Rope* – the simple swipe gesture came naturally. But flicking our way around Google Earth felt alien, with just slight movements making the view zoom in and out too quickly.

For now Leap Motion is a proof of concept that should improve as more apps become available. While gesture control will most likely have a place in hybrid interfaces of the future, we wouldn't ditch the keyboard and mouse just yet. ■

JAMIE CARTER is a freelance technology journalist for CNet

APPLIANCES OF SCIENCE

1 QUIET DOWN

These are the first noise-cancelling earphones that let you choose which sounds you block out. The Bose QuietComfort 20s can isolate and block low frequency sounds like a droning aeroplane engine, leaving high frequency sounds audible. And when you need respite from the crying baby two rows back, they're agile enough to cut out the rapidly modulating frequencies of the human voice.

Bose QuietComfort 20
£259.95, bose.co.uk

2 THAT'S A WRAP

With smartphones and cameras now offering full-HD video, you might think there'd be no need for camcorders. Canon thinks otherwise, with this alternative take on the old handheld. At a mere 76 x 22 x 96mm, the idea is the Vixia Mini can slip into your pocket and offer high-speed, adaptive filming that your phone and compact camera can't. Plus its Wi-Fi mode will let you control filming remotely from your smartphone or tablet.

Canon Vixia Mini
£249, canon.co.uk

3 HEADS UP

Driving a car while squinting at a Sat-Nav that's yelling at you probably isn't the best formula for road safety. This heads-up display connects to your smartphone and projects directions, speed and distance to destination onto your windshield, just like in a fighter plane, so you're not forced to divert your attention from the road. Just don't get too caught up in pretending you're in *Top Gun*...

Garmin HUD
£129.99 + £44.99 app, garmin.com

4 SPECS APPEAL

If you wear glasses every day, then it's important that they fit comfortably. Protos uses smart algorithms to analyse pictures of you and determine what styles of frame will suit your face, and the precise dimensions needed for a snug fit. Once you select a design you like, the frames are then brought to life by a 3D printer using a flexible plastic that's easy to bend but tough to break.

Protos Eyewear
Price TBC, protoseyewear.com

5 KEEP SHARKS IN THE DARK

Above water, this swimsuit might make you look like a beached whale, but in the sea it makes you invisible to sharks. The theory goes that since sharks are colour-blind they won't be able to see a diver in this suit. However, as it's well known that the predators use *all* their senses to hunt, there's also a suit that uses black and white stripes to mimic prey that would be poisonous to eat.

Radiator Elude Dark Diving Suit
AUD 495 (£286) plus P&P, radiator.net

6 PAR FOR THE COURSE

Football and tennis have already had a high-tech makeover with the arrival of smart balls and rackets, and now it's golf's turn. Sensors inside this add-on to your club track its swing and position. This data is recorded and sent via Bluetooth to your smartphone or tablet, where it's drawn into a 3D map of your movements alongside stats on club speed, angle and more. You can then compare stats with other users online.

Swingbyte
£145, swingbyte.com

Sky-Watcher®

SynScan™ AZ GoTo Computerised Telescopes

The exciting new Sky-Watcher SynScan™ Alt-Azimuth GoTo Mount is a Precision Engineered Instrument that will allow you to Easily Find and enjoy viewing Night Sky Treasures, such as Planets, Nebulae, Star Clusters, Galaxies and much more. The SynScan™ AZ hand control allows you point your telescope at a specific object, or even Tour the Night Sky at the touch of a button!! The User-Friendly menu system allows automatic slewing to over 42,900+ objects. Even an inexperienced astronomer can master its variety of features in a few observing sessions. Combined with telescope OTA's of proven High Quality, these Superb Packages are all you need to Explore the Universe to your Heart's Content!!

Prod.Code: 10209

SRP £349

EXPLORER-130P SynScan™ AZ GoTo 130MM (5.1") F/650 COMPUTERISED PARABOLIC NEWTONIAN REFLECTOR (left) Fantastic performance from this highly capable all-rounder. Its precision Parabolic primary mirror captures 30% more precious starlight than a 114mm reflector for bright, sharp, contrasty views of a wide range of night sky objects. Supplied with 10mm & 25mm Eyepieces and 6x30 Finderscope

"Its sharp optics ensure that it delivers bright, diffraction-limited images… In short a great all-rounder in its class" **Ade Ashford, www.scopetest.com**

Prod.Code: 10211

SRP £429

SKYMAX-127 SynScan™ AZ GoTo 127MM (5") F/1500 COMPUTERISED MAKSUTOV-CASSEGRAIN (right) A larger version of the Skymax-102 providing a massive 55% more light-gathering power and packing an even more powerful punch than its smaller cousin for medium-to-high-power work. Supplied with 10mm & 25mm Eyepieces, 90° Star Diagonal and 6x30 Finderscope.

"This is one of the jewels in the Sky-Watcher crown. Its large enough to produce richly detailed, high-contrast, Lunar & Planetary images" **Ade Ashford, www.scopetest.com**

"The new SynScan AZ GoTo offers the key features, upgradeable feature set and ease of use of Sky-Watcher's more expensive equatorial GoTo mounts, in a sturdy, single-arm fork package weighing less than 4.5Kg (incl. Tripod) that has impressive targeting accuracy. Quieter in operation than the competing Celestron SLT and equally capable of external computer control, the SynScan AZ is ideally suited to sub-5Kg grab-and-go instruments with a standard Sky-Watcher/Vixen dovetail bar fitting. Highly Recommended!!" **Astronomy Now Magazine**

STARTRAVEL-102 SynScan™ AZ GoTo 102MM (4") F/500 COMPUTERISED REFRACTOR (below) Ideal multi-coated instrument for the wide-field observation of Deep-Sky objects, such as Nebulae, Star Fields & Clusters and galaxies. A useful telescope for astrophotography and also for daytime terrestrial use. Supplied with 10mm & 20mm Eyepieces, 45° Erect Image Diagonal and 6x30 Finder

"A compact and versatile photo-visual refractor equally at home delivering widefield deep-sky views or exploring terrestrial vistas." **Ade Ashford, www.scopetest.com**

Prod.Code: 10208

SRP £299

SKYHAWK-1145P SynScan™ AZ GoTo 114MM (4.5") F/500 COMPUTERISED PARABOLIC NEWTONIAN REFLECTOR (left) This telescope with its superb parabolic optics provides excellent all-round performance for both the observation of the Moon & Planets and Deep-Sky objects. Supplied with 10mm & 25mm Eyepieces and 6x24 Finderscope.

"The optics were so good…Captures star clusters and brighter nebulae beautifully under dark skies." **BBC Sky At Night Magazine**

Prod.Code: 10207

SRP £349

SKYMAX-102 SynScan™ AZ GoTo 102MM (4") F/1300 COMPUTERISED MAKSUTOV-CASSEGRAIN (right This compact telescope, with it's high-resolution multi-coated optical system, excels at medium-to-high-powers for the examination of the surface detail of the Moon, planets and also for double-star observations. Also useful for terrestrial use. Supplied with 10mm & 25mm Eyepieces, 90° Star Diagonal and 6x30 Finderscope

"Delivers high-contrast, pin-sharp views one has become accustomed to with Sky-Watcher Maksutovs." **Astronomy Now Magazine**

Prod.Code: 10210

SRP £369

Main Features: • SynScan™ Database: Total 42,900+ Objects, including Complete M, NGC, IC & SAO Catalogues • Alignment Method: Two-star or Brightest star alignment • Pointing Accuracy Enhancement (PAE) feature • Unknown Object Indentification feature • Pointing Accuracy up to 10 arc min • Tracking Mode: Dual Axis Tracking • Tracking Rates: Sidereal, Lunar, Solar • Slewing Speeds: 1.0x, 2.0x, 16x, 32x, 64x, 128x, 400x, 500x, 600x, 800x • Quiet Operation • Motor Type & Resolution: DC Servo Motors. Resolution 0.8923 arc sec or 1,452,425 steps/rev • PC Compatible: can be used with popular Planetarium Software • SynScan Handset Firmware upgradeable via the Internet • Power Requirement: 12v DC Power Supply (Tip Positive) or AA Batteries (not supplied)

Sir Patrick Moore Endorses Sky-Watcher Telescopes

"I have used a great number of telescopes; some are good, some mediocre and some bad. To me the Sky-Watcher range of instruments are very good indeed, & suited to amateurs of all kinds – and they are not priced out of the market! Excellent value. Use them and enjoy them."
Sir Patrick Moore CBE FRS (1923-2012)

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ULTIMATE TEST

SPIES IN THE SKY

Small, discreet and easy to fly, the next generation of unmanned aerial vehicles is here. Daniel Bennett prepares for take-off

PHOTO: THESECRETSTUDIO.NET

Aileron
Electric motors adjust each flap independently during flight. As wind hits the wings, the ailerons adjust to keep the LA100 and its camera steady.

Engine
Small but powerful, it will propel the craft to speeds of up to 80 km/h (50 mph) and fly at a height of around 80m.

Unibody wing
With a wingspan of 92cm, this toughened polypropylene frame makes the craft light enough to fly (850g), but tough enough to survive crash landings... which we can certainly vouch for.

GoPro mount
No camera is supplied but you can attach any model of GoPro camera to the nose mount. A GoPro 3 (not older models) is also able to attach to the underbelly of the plane, and film the ground beneath. These will record video in full-HD (1080p) and at up to 60 frames per second.

LEHMANN LA100

lehmannaviation.com, €990 (£854) plus P&P

CUT OUT FROM a single block of light but tough polypropylene foam, the first thing that strikes you about the Lehmann LA100 is just how little it weighs – 850g to be exact. Everything about it has been cut down to the bare essentials. The hull – which houses the GPS unit, flight computer (the LA100 flies on autopilot) and battery – is made out of a single piece of carbon fibre which fastens to the wing with Velcro alone. Simplicity is king here.

It's simple to fly, too. Once the battery's plugged in, the GPS unit rings out for five seconds to let you know it's acquired a satellite fix. Next, a tilt towards the ground instructs the UAV to test out its wing flaps. When that's done, pointing the nose upwards starts a countdown of beeps warning you that the electric motor is about to start. You'll want to be wearing gloves at this point to protect your hand from the whirling propeller. Then, take-off is as easy as lobbing the LA100 into a headwind.

There's a split-second of fear as it immediately falls to Earth. That's swiftly followed by a sigh of relief as it climbs towards the clouds at the last moment. From there the autopilot takes over. It flies off in a straight line for around 300m and ascends to 80m before looping around and tracing a criss-cross pattern in the air over the starting point. Five minutes later it returns and gently spirals back down to the point it launched from.

In strong winds the onboard sensors keep the LA100 flying true and, although it's disappointing not to get a camera included in the price, the footage from the GoPro is spectacular. Ultimately though, there's no practical use here – Lehmann recommends using it for mapping. It's just an expensive toy, but it's an exciting one.

ARE THEY LEGAL?

Toys they may be, but there are a few rules to bear in mind before you take off

The Civil Aviation Authority makes the rules here and its guidelines follow common sense. Your drone must stay at least 150m from a congested area or 50m from potential passers-by, and you should always make sure your drone is in view – no more than 400m horizontally and 400ft (122m) vertically from the pilot.

Surprisingly you're free to film as much you like, as long as the footage is for private viewing only and not for commercial use. And of course you should avoid poking your drone's nose into private property. If you plan to upload footage where individuals are clearly identifiable onto YouTube, you should get their permission first.

PHOTO: THESECRETSTUDIO.NET, ALAMY, TITAN AEROSPACE

Indoor hull
This body is made from a tough but flexible polypropylene foam which keeps its shape after an impact. A more aerodynamic hull is supplied for outdoor flight.

Sensors
Accelerometers and magnetometers monitor the position of each blade, while an ultrasound sensor under the hull checks the Parrot's distance from the ground.

Watch a video of the drones in action on the *BBC Focus Magazine* iPad app and YouTube channel at youtube.com/sciencefocus

Camera
The HD (720p) camera sends a live view to your smartphone, which can then record video or take snapshots. Augmented Reality (AR) games can superimpose virtual fighters over your view or use the Parrot's distinctive markings to identify other drones.

Piloting app
Speed, altitude and piloting controls are all laid over the Parrot's-eye view. The Emergency button lands the drone immediately.

PARROT AR DRONE 2.0

Parrot.com, £299

SEVEN MINUTES OF terror. No, I'm not referring to the Curiosity rover's descent to Mars, but what happened the last time *Focus* tested a remote-controlled helicopter. There was lots of palm-sweat, panic and, ultimately, disappointment when the chopper hit the ground blades-first.

In comparison, flying the Parrot AR Drone is a much more civilised affair. After a breezy set-up – you just download the app from the App Store or Google Play on your smartphone and connect to the drone's own Wi-Fi network – you tap the take-off button and the drone leaps into the air and hovers there like a dragonfly, a metre or two above the ground.

Parrot's quadrocopter can do this because inside its hull its brain is calculating how fast to spin each of its four blades for the entire craft to stay still. If a gust of wind buffets the drone, its sensors tells its 1GHz processor what adjustments to make to stay level. All this wizardry means you can just concentrate on where you want to go, and not worry about smashing into the ground, walls or passers-by.

The piloting app superimposes your controls – a directional pad for each axis – over a live view from the AR Drone's cam. You simply tell it where to fly and it obeys. It'll even pull off flips and barrel rolls at a touch.

This means pointing the 720p HD camera in the right direction is easy enough, while chasing virtual baddies through its Augmented Reality games (AR) is hugely enjoyable.

Sadly the fun is likely to be fairly short-lived as its battery won't survive much more than 20 minutes of flight. But if you've been filming the action, then watching the crisp, smooth footage will occupy your time between charges.

FUTURE DRONES

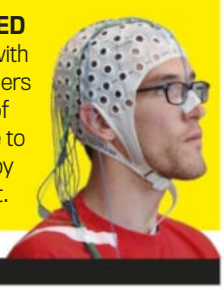
Soon the skies will be buzzing with drones thanks to future applications like these...

SOLAR-POWERED

Pairing the latest solar power technology with a UAV results in a high-altitude plane that can fly for months at a time, functioning as an alternative to GPS satellites.

MIND-CONTROLLED

Using a cap loaded with electrodes, researchers from the University of Minnesota were able to pilot a drone purely by the power of thought.



WHAT CAUSES EARTHQUAKES?

BY ANDREW ROBINSON

They've devastated cities throughout human history, but have proved to be one of the most difficult of natural phenomena to understand

NOT LONG AFTER midnight on an ordinary evening in 2008, I had an uncanny seismic experience. I had just finished drafting a review of a book called *Apocalypse: Earthquakes, Archaeology, And The Wrath Of God* when I felt the floor of my upstairs flat in London shift almost imperceptibly for a second or two. Perhaps the vibration had been caused by a London Underground train, so I forgot about it and went to bed.

The following morning, however, the BBC radio news bulletin announced that there had been an earthquake, at 12.56am. The British Geological Survey had monitored the event as having occurred at a depth of 5km, with its epicentre in Lincolnshire, roughly north of London around 200km away, and with a potentially destructive magnitude of 5.2. One serious injury was reported and many houses close to the epicentre – where the intensity of an earthquake is greatest – suffered damage. This was the biggest earthquake in the UK since 1984.

Every year in Britain, some 200 minor tremors are recorded by seismographs. A magnitude-4 earthquake occurs every two or three years on average; a magnitude-5 quake every 10 years. In 1931, there was a quake of magnitude 6.1 – the largest British earthquake measured to date.

As a rule, 90 per cent of these tremors go undetected by the public. Those that are noticed – like the magnitude-5.2 earthquake on 27 February 2008 – are nevertheless rapidly forgotten. To most people, earthquakes and England would appear to have little connection with the almost apocalyptic earthquakes that have shaped society in countries like China, Japan, Iran and Pakistan, where violent shaking of the earth has killed millions of people in modern times. Yet, it was in Britain that seismology emerged as a science.

The first attempts to account for earthquakes in other than divine terms come from ancient Greece and Rome. Rather than imagining the god Poseidon striking his trident on the ground in anger, some Greek philosophers proposed natural explanations. Aristotle, during the 4th Century BC, believed in a 'central fire' inside caverns in the Earth. As the subterranean fires burned away the rocks, the underground caverns collapsed, generating earthquakes.

Aristotle even classified earthquakes into types according to whether they shook structures and people in mainly a vertical or a diagonal direction, and whether or not they were associated with escaping vapours. Much later, the Roman philosopher Seneca, inspired in part by an Italian earthquake in AD 62 or 63 that devastated Pompeii, proposed that the movement of air – rather than smoky vapours – trapped and compressed within the Earth, was responsible for both violent storms and destructive rock movements.

MADE IN CHINA

The first measurement of an earthquake comes from ancient China, however. The earliest known seismometer was invented in AD 132 by Zhang Heng. It consisted

PHOTO: GETTY

A road is decimated by a magnitude-6.8 earthquake that struck Ojiya, Japan, in 2004, killing 68 people

> IN A NUTSHELL

Once thought to be the work of callous gods, we've gradually come to understand the mechanics of earthquakes to the point where we can accurately measure them and even predict where the next devastating blow might strike.

of eight dragon-heads facing the eight principal directions of the compass. They were mounted on the outside of an ornamented vessel said to resemble a wine jar with an approximate diameter of 2m. Around the base, directly beneath the dragon-heads, were eight squatting toads with open mouths. In the event of an earthquake, a bronze ball would drop from a dragon-head into a toad's mouth with a resonant clang. The direction of the earthquake was probably indicated by which dragon-head dropped its ball, unless more than one ball dropped, indicating a more complex shaking. The device must have comprised a pendulum as the primary sensing element, somehow connected to levers that caused the bronze balls to drop.

According to Chinese history, in AD 138 the seismometer enabled Zhang Heng to announce the occurrence of a major earthquake at Rosei, 650km to the northwest of the Chinese capital Loyang – two or three days before news of the devastation arrived by messengers. This prediction restored the faith of court officials in the seismometer, and led the imperial government to appoint a secretary to monitor the instrument, which remained in existence for four centuries.

But scientific understanding of how earthquakes form had to await the destruction of Lisbon in 1755 by an extremely powerful earthquake followed by a tsunami and fires. In Britain, data on the effects of the Portuguese earthquake were collected from all over the country and abroad by the Royal Society, supplementing that collected after a series of British earthquakes in 1750. John Michell, an astronomer at Cambridge University, took up the challenge of analysing the eyewitness reports, and accounting for earthquake motions in terms of Newtonian mechanics. Michell eventually published an important, if

THE KEY DISCOVERY

The movement of roads, fences and streams crossing the San Andreas Fault enabled Harry Fielding Reid to develop a theory of how earthquakes are triggered

IN 1906, THE San Francisco earthquake produced a surface rupture 435km (270 miles) in length, and wide enough to swallow a cow, according to a famous folk tale of the time. The rupture happened in an area named the San Andreas Fault. To explain it, geophysicist Harry Fielding Reid published his mechanism of 'elastic rebound'.

Reid had noticed that in the years before 1906, roads, fences and streams crossing the fault had been deformed by its movement, and how after the earthquake they were displaced or offset by up to 6.4m. He proposed that before the earthquake, friction between the two sides of the fault had locked part of it, deforming it as the sides moved past each other – until finally the fault snapped. The sides sprang away from each other and they elastically rebounded, creating the surface rupture.

The lower the friction, the weaker the fault and the more easily it would slip, suggested Reid. In places where the friction was of medium size, the fault would slip frequently, producing many small earthquakes. But where friction was high and the fault strong, it would slip only occasionally: there would be few, but large, earthquakes. While Reid's model suffers from serious difficulties, it's still the best that seismologists have.

Around 3,000 people were killed and 80 per cent of the city destroyed as a result of the 1906 San Francisco earthquake

PHOTO: SCIENCE PHOTO LIBRARY X3, SCIENCE AND SOCIETY, US LIBRARY OF CONGRESS

flawed, geological paper, 'Conjectures concerning the cause and observations upon the phaenomena of earthquakes', in the Royal Society's *Philosophical Transactions* for 1760.

He correctly concluded that earthquakes were 'waves set up by shifting masses of rock miles below the surface'. However, his explanation for this shifting relied wrongly on explosions of steam when underground water encountered underground fires.

When the shifting occurred beneath the seabed, Michell also rightly concluded that it would produce a sea wave (a tsunami), as well as an earthquake. There were two types of earthquake wave, he said, once again coming close to the truth: the first was a 'tremulous' vibration within the Earth, followed shortly by an undulation of the Earth's surface.

From this he argued that the speed of an earthquake wave could be determined by its arrival times at different points on the surface. Such times were approximately known from eyewitness reports for far-flung places affected by the Lisbon earthquake, which enabled Michell to calculate a speed for its wave of 1,930km/h.

He was the first scientist to attempt such a calculation – unaware though he was that the speed of seismic waves varies with the types of rock through which they pass. He then went further, by theorising that the surface origin of an earthquake, what we now call the epicentre, could be located by combining the same data on arrival times. Although he curiously chose a different – and inaccurate – way to calculate the epicentre of the Lisbon earthquake (relying instead on reports of the direction of the tsunami), his theoretical principle is the basis of today's method for locating an epicentre.

FINDING THE EPICENTRE

The next major development came in the mid-19th Century from a brilliant Irish civil engineer, Robert Mallet, who had spent two decades collecting data about historical quakes. His catalogue of world seismicity contained 6,831 listings, giving the date, location, number of shocks, probable direction and duration of the seismic waves, along with notes on related effects. In 1858, he travelled to Naples to investigate the destruction wrought by a recent major earthquake.

CAST OF CHARACTERS

Masters of destruction: the minds who unlocked the mystery of earthquakes

Zhang Heng (AD 78–139) designed the earliest recorded seismometer. He was a Chinese astronomer and mathematician. In 138, the seismometer measured a major earthquake far from the Chinese capital, two or three days before news of the earthquake's damage arrived by messenger.

Robert Mallet (1810–81) was an Irish civil engineer and inventor who became interested in earthquakes during the 1830s. He created experimental earthquakes with dynamite, investigated the 1857 Neapolitan earthquake through detailed analysis of its damage to buildings, and compiled world maps that showed earthquakes clustering in mysterious belts.

John Milne (1850–1913), a British geologist and mining engineer, was a professor in Japan from 1876–95. His teaching, the seismographs he designed and his investigation of the 1891 Mino–Owari earthquake established Japanese seismology, while the international earthquake bulletin he issued after his return to Britain led to the International Seismological Summary started in 1918.

Harry Fielding Reid (1859–1944) served on California's state commission to investigate the 1906 San Francisco earthquake. An American geophysicist, he closely examined land movements due to earthquakes over the course of the previous half-century. He then proposed that earthquakes were the result of the 'elastic rebound' of geological faults such as the San Andreas Fault.

Charles Richter (1900–85), like Reid, was an American physicist-turned-seismologist. Working with Beno Gutenberg at the California Institute of Technology, Richter devised a magnitude scale for Californian earthquakes in 1935. Until the 1980s, 'Richter magnitude' was used internationally, but it has now been replaced by a more accurate 'moment magnitude' scale.

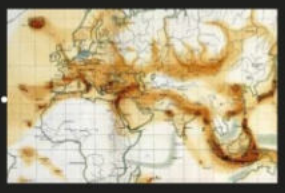
TIMELINE

The key discoveries that have enabled us to understand the mechanism of earthquakes and detect them

AD 132 – The world's first seismometer (pictured), invented by Zhang Heng, establishes the principle that an earthquake can be scientifically measured with an instrument located far from the epicentre.

1755 – A catastrophic earthquake in Lisbon leads John Michell, a British clergyman and astronomer, to conclude, in the Royal Society's *Philosophical Transactions* in 1760, that earthquakes are 'waves set up by shifting masses of rock'.

1862 – Robert Mallet publishes his two-volume study, *Great Neapolitan Earthquake*, and maps of world seismic intensity demonstrating that earthquakes cluster in certain belts around the Earth.



1906 – An earthquake in San Francisco and a subsequent fire destroy the city but establish the discipline of seismology in California. Harry Fielding Reid proposes the 'elastic rebound' theory of earthquakes, which is still influential, if flawed.

1935 – Charles Richter, following the 1933 Long Beach earthquake near Los Angeles, creates a magnitude scale, which enables seismologists to allot a size to each Californian earthquake, regardless of its varying intensities.

1960s – The theory of plate tectonics explains why the vast majority of earthquakes cluster in belts, at plate boundaries such as the 'Ring of Fire' around the Pacific Ocean; but it fails to explain intra-plate earthquakes, for example in Missouri.

PHOTO: SCIENCE PHOTO LIBRARY X2, GETTY X3, US LIBRARY OF CONGRESS, PRESS ASSOCIATION

Assessing every crack with a trained eye, Mallet compiled isoseismal maps: that is, maps with contours of equal earthquake damage/intensity. It's a method employed today, albeit with refinements, to map seismic hazard. Mallet placed too much reliance on the direction of fallen objects and the type of cracks in buildings as indicators of earthquake motion (cracking is in fact mainly a function of the type of building construction). But his maps did allow him to estimate the centre of the earthquake and its size relative to other earthquakes.

Using the new technique of photography, he documented the damage. He then reported to the Royal Society in a two-volume study, *Great Neapolitan Earthquake Of 1857: The First Principles Of Observational Seismology*, published in 1862. Elsewhere, he published maps of world seismic intensity, providing the first indication that earthquakes cluster in certain belts around the Earth. An explanation of this fact would have to wait another century, but in the meantime Mallet's map focused scientific attention on these patterns.

GLOBAL NETWORK

Over the next half-century seismology became a truly international science, as measuring instruments improved in sensitivity to the point where they were able to monitor, and record, earthquakes all over the planet from a single location. A British geologist and mining engineer, John Milne, having designed more than one such seismograph while living for two decades in Japan, returned to Britain in 1895 and established a central earthquake observatory at his house on the Isle of Wight. It had inputs from a worldwide network of seismographic stations. Although Milne's theoretical contributions were small, he has a considerable claim to be considered the founder of seismology.

With the vast increase in seismic data, theoretical understanding advanced in the first decade of the 20th Century. The theory that volcanic action might be related to earthquakes – believed by Aristotle and lent credence by the contiguous volcanoes and earthquakes of southern Italy and Japan – was largely abandoned when it became clear that active volcanoes were often free from earthquakes.

NEED TO KNOW

Key terms that will help you understand earthquakes

1 EPICENTRE
The area of origin of an earthquake underground is its hypocentre or focus. The point on the Earth's surface immediately above the hypocentre is the epicentre, where there is often visible movement and cracking of the Earth, as surface waves radiate from the epicentre.

2 FAULT
At its simplest, a geological fault is a joint between two rock planes. The fault is usually not exactly vertical and so one plane of the fault overhangs the other. Fault movements and earthquakes are intimately connected, but their precise relationship is controversial.

3 INTENSITY
The intensity of an earthquake measures its effects on objects, humans and animals. Intensity generally increases the closer the observer is to the epicentre. It's also higher for a poorly constructed building than for a well-built one, given the same shaking.

4 MAGNITUDE
Unlike intensity, magnitude is independent of the observer's distance from the epicentre. It is, so to speak, the amount of explosive in a bomb, as opposed to the bomb's effects. An earthquake can have only one magnitude, fundamentally; but it always has many intensities.

Charles Richter studies earthquake tremors in his laboratory in Pasadena, California – he developed the Richter scale in 1935

Instead, the tectonic movement of geological faults came to be seen as the chief origin of earthquakes. Known as the 'elastic rebound' model, abrupt fault movement was first proposed by the American geophysicist Harry Fielding Reid in 1906 to account for the surface rupture of the San Andreas Fault in the San Francisco earthquake (see 'The Key Discovery', p90).

But while the model was plausible enough, it offered no explanation as to why the sides of certain geological faults should be grinding past each other in a regular fashion, causing periodic earthquakes. What force was driving them? Not until the 1960s, with the advent of plate tectonic theory, did seismologists appreciate that the San Andreas Fault was the boundary between two tectonic plates, the Pacific plate and the North American plate, which were moving in opposite directions. Some other plate boundaries, for example near Japan, were also seismically active. Hence the fact, first noted by Mallet, that earthquakes clustered in bands, which were now understood to coincide with plate boundaries.

Yet, despite progress, seismologists remain far from fully understanding earthquakes. Plate tectonics do not really explain British earthquakes, far from the mid-Atlantic plate boundary. What's more, geological faults such as the San Andreas have turned out to be very much weaker than would be expected from the elastic rebound model for large earthquakes.

As for earthquake prediction, which was touted by many seismologists as achievable during the last few decades of the 20th Century, all seismologists now admit it's currently impossible. The scale of the task was outlined by Charles Richter, who devised the 'Richter' magnitude scale for measuring earthquakes in the 1930s. The seismologist said: "One may compare it to the situation of a man who is bending a board across his knee and attempts to determine in advance just where and when the cracks will appear." ■

Andrew Robinson is the author of *Earthquake: Nature And Culture* and *Earthshock*

Find out more

BBC WORLD SERVICE *Forecasting Earthquakes* reveals the past, present and future of earthquake detection.
www.bbc.co.uk/programmes/p01c4qgt

TO DO LIST

PLAN YOUR MONTH AHEAD WITH OUR EXPERT GUIDE

VISIT
WATCH
LISTEN
TOUCH
PLAY
READ

PICK OF THE MONTH

Hawking

This new film offers a fresh perspective on the life of the most famous living scientist

IN THE OPENING scene of *Hawking*, the famous physicist is about to take the stage at a public lecture, his face obscured by the screen with which he selects words to be spoken by a synthesizer. It symbolises how the wheelchair, the voice and Hawking's iconic status have come to overshadow the man himself.

This, then, is an attempt to show what life is like for a 71-year-old who has overcome every obstacle since being diagnosed with motor neurone disease a staggering 50 years ago. Scenes of Hawking at home and work are cut with contributions from his family, friends and colleagues. Most poignant are the recollections of his first wife, Jane. His illness was already diagnosed when they first met, yet she devoted herself to their marriage and three children. But after a succession of health scares, the couple bowed to the inevitable and hired round-the-clock carers. Hawking survived, but their marriage didn't.

By the time the couple split up in 1990, Hawking was a superstar, able to do pretty much anything he liked. We see footage of him on *Star Trek* and *The Simpsons* and his flight in NASA's 'vomit comet'. Richard Branson even pops up to say he's offered Hawking the first trip to space on Virgin Galactic.

If all this is standard autobiographical fare, it's still a revelation to see Hawking's humorous side. Fellow students at Oxford remember him as the life and soul of every party, and a master of witty one-liners.

The biggest disappointment is that his scientific discoveries aren't better explained. It's possible to appreciate that Hawking's studies of black holes showed how the Big Bang could produce the Universe. Yet his other work on black hole mergers and Hawking radiation is rather baffling, and largely left to colleagues to put in context. It's a shame because Hawking is clearly driven by his craving to understand the Universe.

This film is still worth watching, though, for its candid glimpses of an extraordinary man who plays Wagner at full blast while continuing to defy the odds.

GRAHAM SOUTHORN

***Hawking*, directed by Stephen Finnigan, is in cinemas from 20 September**

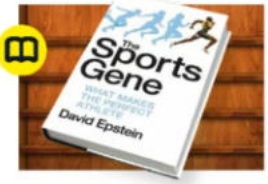
DON'T MISS!

Ada Lovelace Day Live

An evening at Imperial College London celebrating the work of the many largely unsung female scientists in history. p96

Take On Mars

Get behind the wheel of your very own Mars rover with this extra-terrestrial driving sim. p101



The Sports Gene

This new book examines whether great athletes are born or made. Does the key to their success lie in their genes? p102

PHOTO: GETTY

VISIT

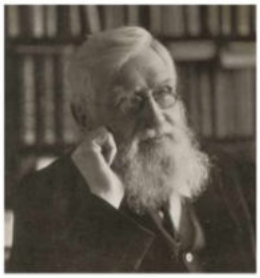
EVENTS & EXHIBITIONS

WITH JHENI OSMAN

OCTOBER-JANUARY

Wallace100

Swansea Museum, www.swanseamuseum.co.uk



FORGET DARWIN FOR once: 2013 is the year to celebrate the achievements of Alfred Russel Wallace, the Welsh naturalist who co-founded the theory of evolution by natural selection. This exhibition, marking 100 years since his death, follows his story from a childhood in Usk to his eventual exploration of the Amazon and Indonesia.

3 OCTOBER-24 NOVEMBER

Echo

FACT Liverpool, www.fact.co.uk

EVER SEEN YOUR doppelgänger? You can with this video installation, where a 'reflection' of yourself moves and speaks as you do in real time, but within an unfamiliar city. The installation was developed with Professor Olaf Blanke, Director of the Laboratory of Cognitive Neuroscience at the Brain-Mind Institute in Lausanne, Switzerland.

5-20 OCTOBER

Midlothian Science Festival

Various venues and prices, midlothiansciencefestival.com

Get up close to your body... extremely close, by using a microscope to look at your own cells. This is just one of the quirky events at this festival. There's also hands-on experiments with the Chemistry Brothers and the return of *Brainiac*'s Dr Bunhead (pictured), exploring everything from bubbles to bombs in an explosive show.

PHOTO: ALAMY, SCIENCE AND SOCIETY, ASA JOHANNESSON, BAS

JHENI OSMAN is a science writer and the author of *100 Ideas That Changed The World* (BBC Books, £9.99)

Scientists haven't always worn lab coats you know

EDITOR'S CHOICE

15 OCTOBER

Ada Lovelace Day Live

Imperial College London, 6pm, £15, findingada.com

WHO WAS THE world's first computer programmer? A strong case can be made for the 19th-Century countess, writer and mathematician Ada Lovelace. She was famed for her contributions to Charles Babbage's early mechanical computer, the Analytical Engine.

Her father, the poet Lord Byron, was a philanderer who sired more children out of wedlock than in – mainly because he upped sticks and left the UK four months after Ada was born. Deeming him mad, and not wanting her daughter to follow his 'delusional' way of life, her mother encouraged Ada's interest in mathematics to keep her mind on the logical straight and narrow. Nowadays, Ada Lovelace is seen as something of an iconic figure, representing the many other historical female scientists who had the glory stolen from them.

To shine the light on women working in science, technology, engineering and mathematics today, attendees of this event are encouraged to share stories of those who have inspired them. The host, science comedian Helen Arney, is joined by female scientists to celebrate Ada's achievements and all she stands for.

19-20 OCTOBER

Battle Of Ideas

The Barbican, London, www.battleofideas.org.uk

THE BARBICAN HOSTS its annual festival of debate to get the mental cogs whirring. With over 80 sessions, there's plenty of food for thought, and of particular interest to the scientifically curious will be debates on the science of addiction, legal highs, the obesity crisis and the ethics of Big Data. Grey cells at the ready, science-slingers!

21 OCTOBER-6 JANUARY

Ice Lab

MOSI, Manchester, www.mosi.org.uk

THE LOWEST TEMPERATURE ever recorded in Antarctica was -89.2°C, while winds can reach 320km/h (199mph). Designing research stations to cope with these extreme conditions takes some serious engineering. This exhibition showcases Antarctic architecture, as well as looking at the science taking place in the frozen wasteland.

23-30 OCTOBER

London Science Festival

Various venues and prices, www.londonsciencefestival.com

AT 150 YEARS of age, the Tube is the world's oldest underground train system. London's festival celebrates this and other technological and engineering achievements. Speakers include leading scientists and engineers, familiar faces from the small screen such as Adam Rutherford and, slightly randomly, comedian Ruby Wax.

25 OCTOBER - 19 JANUARY

Grow Your Own...

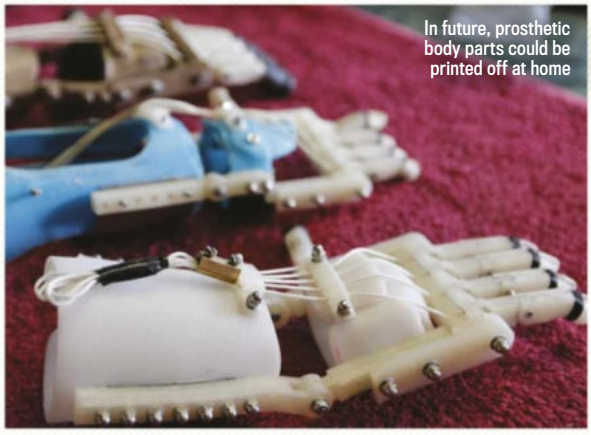
Science Gallery, Dublin, sciencegallery.com

BIOBRICKS ARE OPEN source DNA 'building blocks' that were first developed at Massachusetts Institute of Technology 10 years ago. But in the wake of all the furore around GM food, their use by genetic scientists has proven equally controversial. This exhibition tackles provocative questions surrounding synthetic biology – see p57 for more.

FROM 9 OCTOBER

3D: Printing The Future

Science Museum, London, 10am-7pm, free, www.sciencemuseum.org.uk



In future, prosthetic body parts could be printed off at home

THIS NEW EXHIBITION, which will run for nine months, looks at the growing impact of 3D printing on everything from medicine to aeronautical engineering. This rapidly evolving technology could soon be used to 'print' replacement organs and create drugs specifically targeted to the patient's body. It's already being used to build lighter parts for aeroplanes and space probes. Prop-maker Ivan Owen helped carpenter Richard Van As, who lost four fingers in an accident, design and build a mechanical hand – the plans have already been downloaded over 27,000 times from Thingiverse.com. Visit the Science Museum to see this 3D future, and find out if it works.

SPEAKER OF THE MONTH

22 OCTOBER

Prof Robert Winston

Westminster Abbey, London, 6.45pm, £27, www.intelligencesquared.com

Who is he?
The man with the distinctive moustache, Prof Winston is currently Professor of Science and Society at Imperial College London.

What's his background?
Prof Winston (aka Lord Winston) set up the IVF service at Hammersmith Hospital. He's been a scientific advisor to the World Health Organisation and has presented many BBC series, from *Child Of Our Time* to *Walking With Cavemen* and *The Human Body*.

What's he talking about?
Prof Winston joins Jack Straw and Max Hastings in the debate 'An Anatomy Of Truth', looking at whether telling the truth is always the best thing to do. If you ask us, a little white lie never hurts, does it?

WATCH

TV, DVD, BLU-RAY & ONLINE

WITH TIMANDRA HARKNESS

SEPTEMBER

Animal Maternity

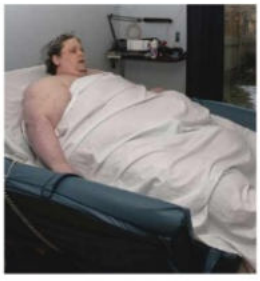
Channel 5, September TBC

BEHIND-THE-SCENES hidden cameras at zoos, wildlife sanctuaries and safari parks witness the births of some of the rarest creatures on Earth, including zebras, elephants, and white rhinos. But as every parent knows, that's just the start of the work: we still have all the sleepless nights, the feeding and baby's first steps to go.

SEPTEMBER

Supersize Season

Channel 5, September TBC



WITH CHRISTMAS EXCESS looming, here are six documentaries to put the frighteners on you. Keith weighs almost 70 stone, and he's out to lose half his body weight and walk his dog again. But it's not always a simple journey. Other would-be slimmers suffer unwanted side effects from weight-loss surgery, or find their love lives hit by unexpected fallout.

FROM **26** SEPTEMBER

Animal Airport

Animal Planet, 26 September, 8pm

CHICKENS AT CHECK-IN, baggage-handling baboons and penguin pilots? Sadly, no. It's a fly-on-the-wall series from Heathrow's Animal Reception Centre, which welcomes 40 million animals a year. In the first episode, "Ross tackles a particularly angry cat, the life of a monkey is in Stuart's hands and Sian takes on some unruly alpacas." Beat that, *Friends*.

TIMANDRA HARKNESS is a stand-up comedian and a presenter on BBC Worldwide's YouTube channel Head Squeeze

PHOTO: DISCOVERY NETWORKS X2, NATIONAL GEOGRAPHIC CHANNEL, GETTY, CHANNEL 5

EDITOR'S CHOICE

Being Bono's stunt double is a dirty job but someone's got to do it

2 SEPTEMBER

Man Vs Ride

National Geographic, 30 September, 10pm

NEIL COKE HAS bagged one of the best TV jobs going. His mission: to ride the world's most thrilling rollercoasters in the name of science. So from Ferrari World in Abu Dhabi to a disused mine shaft in South Africa, Neil goes there on our behalf. He even takes one for the team by driving a Ferrari around a nearby race track to compare the speed and acceleration of car and ride.

Of course, there are downsides. Cameras on-hand to record every adrenalin-packed moment also capture each twitch of terror, nausea, and unflattering face-flapping. He competes against a teenage rugby team to hold out against the vomit-inducing powers of Spain's eight-inversion 'coaster Dragon Khan, repeating the ride time after time until only three of them are still capable of keeping their dinners down. And he bravely faces up to his own biggest fear.

If you're worried that lengthy explanations of the science will get in the way of thrilling rollercoaster footage, don't be. To get a proper understanding of any of the fascinating science, engineering and medicine touched upon in the stunts and demonstrations, you'll need to head to Google or ask a science teacher. Which is a pity, as there is plenty of physiology, psychology, physics and mathematics involved in ride design.

But it's an hour packed with entertainment, visuals and vicarious thrills, and Neil is an engaging presenter – with an above-average ability to withstand G-forces. Though as he learns, that's not entirely a good thing...

FROM **30** SEPTEMBER

Ultimate Survival Alaska

Discovery, starts 30 September, 8pm

THIS SERIES DROPS eight survival experts in the middle of Alaska with only the gear they can carry. Crossing mountains and glaciated river valleys, they must face hunger, predators… and each other. Ten stages will test them physically and mentally, with gruelling time limits to beat on the long way home: think *Big Brother* with snow, ice and bears.

OCTOBER

The Great British Year

BBC, October TBC

IT SOMETIMES FEELS as if British weather follows no discernible pattern except to rain whenever you go out without a coat. But in this series, four hour-long programmes trace the landscape and wildlife of Britain over a year, using time-lapse photography to make visible the subtle changes we often miss, such as the spectacular aurora borealis.

FROM **25** SEPTEMBER

How It's Made: Dream Cars

Discovery HD, starts 25 September, 8pm

How It's Made explores the art and science that goes into building a supercar

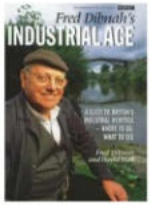
YOU MAY NEVER be able to afford a Porsche 911, let alone a Morgan Aero Coupe, but thanks to this series you can get under the bonnet and right inside all the nooks and crannies. From the choice of materials to the way the instruments are arranged on the dashboard, every detail of the engineering contributes to these cars' overall impact. Follow every step of the process, from lumps of steel arriving in the factory to rubber tyres hitting the road.

DVD & BLU-RAY

Race To The Moon

Go Entertain, £8.30

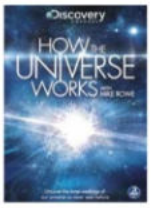
WHEN APOLLO 11 landed on the Moon, Russia already had its own rocket on the launchpad. This Russian-made documentary uses rare footage, interviews and expert analysis to tell the Moon race story from the Russian point of view.



Fred Dibnah's Industrial Age

Demand Media, £20

In this series from 1999, the late Fred Dibnah visits 200 locations to meet people who worked in coal mines and cotton mills, as well as the volunteers who restore ships and steam engines, while animations show how the engineering worked.



How The Universe Works

Discovery, £13.30

This show aims to explain the Universe in terms of a huge mechanical device, with stars, black holes and galaxies working together to produce the cosmos we see today. With cutting-edge CGI, take a journey from the Big Bang to life on Earth.

OCTOBER

Monster Moves

Channel 5, October TBC

IF YOU'VE JUST shifted three books and a lava lamp into a student flat, spare a thought for those moving heavier loads, such as two steam locomotives that are crossing the Atlantic. And if you've ever battled to fit a sofa into a van before unbolting the arms, you'll empathise with the engineers who have to dismantle a helicopter to fit it inside an aeroplane.

OCTOBER

The Man Who Doesn't Breathe

Quest, October TBC

HOW LONG CAN you hold your breath underwater? A minute? Three? Stig Severinsen's personal best is 22 minutes. This two-parter follows him to Greenland, where he hopes to set two new world records: longest dive under ice, and longest underwater breath-hold. For maximum impact, watch it from a bath full of ice cubes. With a walrus.

LISTEN

BBC RADIO PROGRAMMES

WITH TIMANDRA HARKNESS

FROM 10 SEPTEMBER

Shared Planet

BBC Radio 4, 10 September, 11am

MORE FROM THE series that looks sternly over its glasses at the human race and tells us to go and have a long, hard think about what we've done. Like the time we accidentally introduced brown rats to South Georgia, and they ate all the seabird eggs and chicks. Whoops. Can we put that one right? Let's find out.

South Georgia is undergoing the biggest rodent eradication ever undertaken

28 SEPTEMBER

Blind Man Roams The Globe

BBC Radio 4, 28 September, tbc

IMAGINE STEPPING OUT of a distant airport for the first time and meeting a new country through sound, smell and sensation instead of sight. Presenter Peter White, who has been blind since birth, lets us experience the world's cities though his ears and helps us understand the diverse soundscapes that are his introduction to new places.

9 OCTOBER

The Station

BBC Radio 4, 9 October, 11pm

SOUND RECORDIST CHRIS Watson normally captures birdsong and elusive wildlife. But as a regular traveller via Newcastle Upon Tyne station, he wanted to capture the life that happens there. From a lone robin at dawn to the human chaos of rush hour and back to the thundering of overnight goods trains, this is his 24-hour portrait in sound.

Let's hope *The Station* isn't cancelled due to the wrong type of radio waves

19 OCTOBER

Don't Log Off

BBC Radio 4, 19 October, tbc

CONTRARY TO ALL advice, Ian Dein *does* talk to strangers. He uses Facebook and Skype to contact people all over the world, sparking conversations that can be funny, intimate and warmly human, and often hearing the kind of stories that you would only dare to share with someone that you're never likely to meet.

FROM 27 OCTOBER

Living World

BBC Radio 4, 27 October, 6.30am

THE RETURN OF the wildlife series that sends presenters around the UK to report on what's new in nature. So new, we don't yet know where or what, so keep an eye on the BBC Radio 4 website, where you can also see photos of what happens during a recording. Don't be scared of the big furry thing – that's just the microphone. They disguise it as Bill Oddie's chin to avoid frightening the birds.

PHOTO: NASA/JWAP
PHOTO: THINKSTOCK, DREAMSTIME

TOUCH

SMARTPHONE & TABLET APPS

WITH CHRISTOPHER PHIN

IFTTT

iPhone, iPod touch
IFTTT, free

EVER WISHED AN app would just do that one thing it currently doesn't? Or that you could hook up one of your favourite services with another to do something awesome? You need IFTTT. Using this app, you can create 'recipes' that follow the simple programming formula, 'If this, then that'. For example, 'If I favourite a tweet, then add it to a new line of a spreadsheet on Google Drive'. You can make your own recipes knitting together different services, or pick from those others have shared, such as one that will automatically download Facebook pictures you're tagged in to Dropbox.

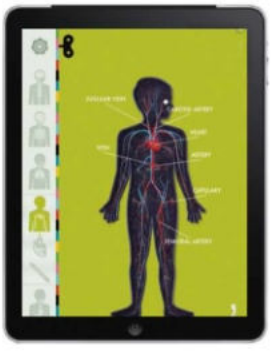
MeteoEarth

Android 4.0.3 or later
MeteoGroup, £1.52

THIS NEW APP from the makers of the popular WeatherPro is beautiful. You can switch between viewing temperature, rain, cloud cover or wind, and for each you can play the forecast forward or scrub back and forth manually; in either case, the animation is buttery smooth. What's more, you can pinch to zoom in and out. This enables you to either see what the local weather's like or get a global perspective on macro weather patterns. Plus, you can switch between 3D and 2D maps.

The Human Body By Tinybop

iPad
Tinybop, £1.99



THIS PRETTY APP is designed to help kids explore the human body. Six layers – skeletal, muscular, nervous, circulatory, respiratory and digestive – teach basic human anatomy, and you can toggle text labels on and off. Kids will love poking around the app, and if you enable the parent function, they can record questions as they're using it which you can review and then investigate with them later.

CHRISTOPHER PHIN is the editor of *MacFormat* magazine

PLAY

CONSOLE & COMPUTER GAMES

WITH NEON KELLY

FIFA 14

PC, PlayStation 3, Xbox 360, EA Sports, £39.99

THE UNDISPUTED KING of football games is back, and this year it's making a surprisingly strong claim to genuine innovation. The new Player Chemistry feature lets you fiddle with the playing styles of individual team members, tailoring their approach to each match. You might give your striker added defensive capabilities, perhaps, or make your defender more aggressive so he's more useful when pushing forward. It's probably best to avoid any settings that encourage biting other players.

Metal Gear Solid: The Legacy Collection

PlayStation 3, Konami, £34.99

BLIMEY, HOW DOES one summarise the importance of Hideo Kojima's epic series in just 80 words? It's not possible, but suffice to say that this compendium houses some of the best video games ever made. Imagine James Bond meets Bear Grylls in a self-aware soap opera, filled with robots, ninjas and edible snakes. Oh, and *Metal Gear Solid 3* has an incredible bit where you simply climb a ladder for two minutes. It's brilliant, honestly.

Disney Infinity

PC, PlayStation 3, Xbox 360, Wii, Wii U, 3DS, Disney, £49.99 (game), £29.99 (playset)

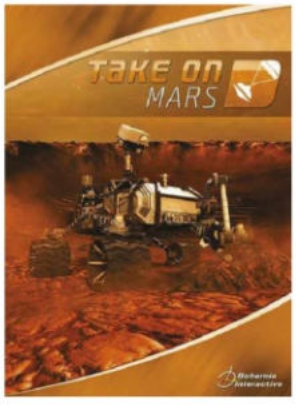
IF YOU'RE FAMILIAR with Activision's wildly lucrative *Skylanders* brand, you'll understand the gist of *Disney Infinity*. It's a platform game where players can scan real-world toys to import them into their virtual worlds. There are also franchise-specific playsets that unlock famous Disney locales like *Monsters University* or the tropics of *Pirates Of The Caribbean*, while Toy Box mode lets you blend characters and settings to create your own mash-ups – like *The Incredibles* battling Davy Jones in Radiator Springs.

NEON KELLY IS DEPUTY EDITOR AT VIDEOGAMER.COM

Scratching your new motor won't just mean a polish job in *Take On Mars*; it means billions of wasted dollars and funding pulled from future missions at the cost of thousands of jobs

Take On Mars

PC, Bohemia Interactive, £8.99



HAVE YOU HEARD of the Mars Curse? No, sadly it has nothing to do with people choking to death on chocolate bars. It's a term that was coined to describe the awkward history of our attempts to explore the mysterious Red Planet. Almost 60 per cent of our missions to Mars have resulted in failure: the batteries went flat on the satellite Mariner 3; Phobos 1 was lost in space; and, of course, there are British physicists who still weep into their tea at the mere mention of the word 'Beagle'. Stupid craters.

Now, thanks to *Take On Mars*, you can try to succeed where others have failed. Assuming the role of a sweaty-palmed operator back on Earth, you'll assume control of your own Rover as you explore the Martian surface. Players can jump straight into a series of missions or otherwise elect to manage an entire space programme from scratch, researching new tech as the funding trickles in. Provided that you don't prang your billion-dollar craft on a rock, that is.

Czech developer Bohemia Interactive is best known for its terrifyingly realistic military simulations – back in 2011, footage from *ARMA 2* was mistakenly used in a TV documentary. While its efforts here are certainly less violent than usual, there's still something quite eerie about your slow progress across the amber dunes, especially when viewed through the warped perspective of a Rover's fish-eye lens.

The vehicles are constructed from up to 50 separately modelled components, any of which might fail on you at a crucial moment: if a wheel gets jammed, for example, you'll have to find a way to compensate for your wonky steering. This kind of problem-solving gameplay might not appeal to everyone, but hey – you can't have a Rover sim without the Mars Curse.

READ

THE LATEST SCIENCE BOOKS REVIEWED

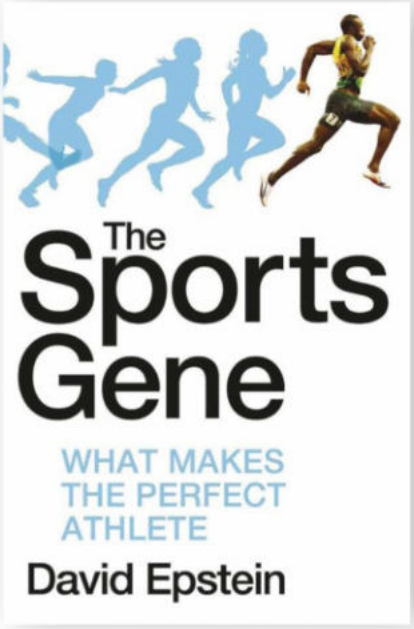
H Hardback P Paperback

The Sports Gene

EDITOR'S CHOICE

David Epstein

Yellow Jersey Press H £16.99



BACK IN 2007, UK Sport launched its Sporting Giants development programme. The aim: to unearth future Olympic talent in sports where height and power provide a competitive advantage. Applicants had to come from an athletic background, be tall – 6ft 3in (1.9m) minimum for men, 5ft 11in (1.8m) for women – and be aged between 16 and 25. Results were mixed but one stood out: Helen Glover's gold in rowing (alongside Heather Stanning) at the 2012 Olympics. Glover passed the necessary physical and performance tests in 2007 and via a monastic lifestyle, sports science support and 40 hours' training a week helped GB women's rowing win their first-ever Olympic gold. Her natural physiology flourished in this world-class sporting environment – a fine of example of nature and nurture working together.

Focusing on the genetic side of the nature versus nurture debate is the goal of *Sports Illustrated*'s David Epstein. Through interviews with the world's leading genetic scientists, exhaustive research and conversations with Olympic champions, Epstein examines the genetic argument behind elite performance. Why long limbs and thin calves explain the Kalenjin people's dominance of endurance running for the last 30 years. How West African slaves with sickle cells and a will to survive laid the foundations for Usain Bolt's super-human sprint prowess. Or how the Chinese basketball federation 'forced' the relationship of former pro basketball players Yao Zhiyuan and Fang Fengdi, who gave birth to NBA legend Yao Ming (7ft 6in, or 2.3m). Along the way, Epstein also exposes some myths including why Malcolm Gladwell's oft-quoted 10,000 hours of practice should be renamed the '7,000-40,000-hour rule'.

"West African slaves with sickle cells and a will to survive laid the foundations for Usain Bolt's sprint prowess"

Epstein looks at all of the components of sporting success – including speed, power, endurance, reaction times and motivation – marrying fascinating anecdotes with cutting-edge science. While at times not as accessible as Matthew Syed's *Bounce*, which dissects peak performance in a wider context, it remains a worthy addition to an expanding area of sporting literature.

Of course, the fear is that genetic doping will soon take centre stage in the sporting amphitheatre, if it hasn't already – note the column inches questioning the meteoric rise of 16-year-old Chinese swimmer Ye Shiwen. If you want to stay abreast of the rapid developments in sports science, fair or not, *The Sports Gene* is a must.

■■■■■

JAMES WITTS is a sports journalist with a degree in sports science

MEET THE AUTHOR

David Epstein

Why did you write the book?
I wanted to explore what genetics can tell us about the biggest nature vs nurture questions in athleticism. The answers to some of these questions were very counter-intuitive to me. Some things that I thought would be genetically-based – like a cricket player's ability to react to speeding objects – turned out to be learned skills, while other things I thought would be unrelated to genetics – like the compulsive drive to train – actually have important genetic components.

Are sports stars successful because of an innate talent, or just because they train very hard?
A bit of both. Practice matters – if it didn't, athletes could just show up on the day without practising. But genetics is showing us that, in many cases, what's more important is the biological setup that allows someone to benefit from their training. Bradley Wiggins, for example, clearly puts in huge amounts of gruelling practice, but studies have shown that elite endurance athletes like him also have gene variants that predispose them to respond well to aerobic exercise.

Is there a genetic explanation for why so many of the world's fastest men come from Jamaica?
It's partly genetics and partly culture. Many Jamaican 100m runners have their ancestry in a relatively small region of West Africa, where people tend to have longer legs in proportion to their body size and a high proportion of fast-twitch muscle fibres. But Jamaica also has an amazing talent selection system that spots great sprinters early, allowing them to make the best of the talent they have.

MORE ON THE PODCAST
Listen to the full interview with David Epstein at sciencefocus.com/podcasts

The Neanderthals Rediscovered

How Modern Science Is Rewriting Their Story

Dimitra Papagianni and Michael A Morse

Thames & Hudson £18.95

THIS IS THE most up-to-date account of the Neanderthals you will find in popular science literature, as Papagianni and Morse outline the latest research into Neanderthal evolution and strive to change the their popular image.

The chronologically-ordered book lets you see the Neanderthals as part of the whole story of human evolution. It starts by discussing *Homo heidelbergensis*, the ancestor of both modern humans and Neanderthals, and goes on to reveal how recent advances, particularly in dating and DNA research, have changed our views. The book breaks down the differences we once thought existed between Neanderthals and ourselves and focuses throughout on the question, "Why us and not them?" The last chapter describes Neanderthals in popular media and how they have turned from dim-witted brutes into well-organised hunters and gatherers, skilled makers of tools and clothes who had language, just like us.

Although it may be less captivating to scientists who are looking for a fully referenced book, it's rewarding if you're interested in Neanderthals and human evolution in general.

■■■■□

ISABELLE DE GROOTE is an anthropologist at Liverpool John Moores University

The Cancer Chronicles

Unlocking Medicine's Deepest Mystery

George Johnson

Bodley Head £18.99

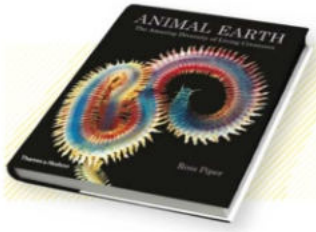
IN 2000, CANCER researchers Douglas Hanahan and Robert Weinberg stated: "One day, we imagine that cancer biology and treatment – at present, a patchwork quilt of cell biology, genetics, biochemistry, histopathology, immunology and pharmacology – will become a science with a conceptual structure and logical coherence that rivals that of chemistry and physics." In a bold and wide-ranging analysis, award-winning science writer George Johnson looks at how science is taking on this challenge.

The author touches upon many aspects of cancer research: proteomics, epigenetics, evolutionary biology, game theory and even extraterrestrial biology (where renowned cosmologist Paul Davies has a theory of cancer). *The Cancer Chronicles* also looks at the politics of cancer, including the role of the charities and why breast cancer, in particular, has such a high profile. And finally this is a personal book, for both Johnson's wife and brother had cancer, which he writes about movingly.

Since more than one in three of us will develop cancer, a better understanding is crucial. This book certainly provides it.

■■■■■

SUSAN ALDRIDGE is a science writer and former medical researcher



Animal Earth

The Amazing Diversity Of Living Creatures

Ross Piper

Oxford University Press £29.95

THIS BOOK IS stunning. *Animal Earth* combines gorgeous photography and up-to-the-minute scientific accounts of all of the world's animals, including information on their ecology, behaviour and genes. Unusually, Piper gives equal space to each of the 35 major lineages, so humans and other vertebrates get a mere 14 pages – without a panda or other 'poster species' in sight. Like most of the book, 'our' section highlights aquatic organisms – lampreys, rays and axolotls.

Piper's organisation of the animal kingdom is novel for a coffee table book, but justified: if we want to explore animal diversity then we need to study marine invertebrates, which show an incredible range of body plans. You may not have heard of many of the animals described here, but you will be amazed at their beauty and their exquisite adaptations.

The text is clear, well-organised and takes account of the latest molecular data, including the recent realisation that insects are simply a kind of crustacean. Piper also addresses one of biology's great mysteries – why are there no insects in the sea? – and gives the right answer: no-one really knows.

■■■■■

MATTHEW COBB is Professor of Zoology at the University of Manchester

The Compatibility Gene

Daniel M Davis

Allen Lane £20

THE IMMUNE SYSTEM does more than protect us against disease. In many ways, most of them still unexplored, it's involved in how we choose our life partners, how we make sense of the world, even how we think. It has shaped many aspects of our evolution and contributes to human diversity. It determines who will live, and who will die. It is also so complicated that trying to grasp any more than the basics can be as hard as nailing jelly to the ceiling.

This explains why few popular books exist on immunology compared with, say, human evolution or quantum mechanics. In fact, anyone who delivers a book about immunology for a general audience deserves two stars just for trying. Davis easily picks up another three for the quality of his writing, his humour and his enthusiasm. To be sure, parts of this book require more than the usual amount of concentration, but that's to be expected. What scores, though, is his humanity – and the wonderful pen-portraits of the many scientists involved in this fast-moving field.

Sure, it's messy – but so's the subject. In real science, no-one looks for easy answers at the back of the book.

■■■■■

HENRY GEE is an evolutionary biologist and a senior editor of the journal *Nature*

FOCUS
SCIENCE AND TECHNOLOGY

NOVEMBER ISSUE ON SALE 17 OCTOBER

PLUS
Alfred Russel Wallace and the other pioneers of evolution

THE FUTURE OF US
HOW THE HUMAN RACE WILL EVOLVE

PHOTO: ALAMY

MINDGAMES PUZZLE SOLUTION
No cheating! Don't look at this until you've attempted the puzzle on p111

THE NORTHERN LIGHTS

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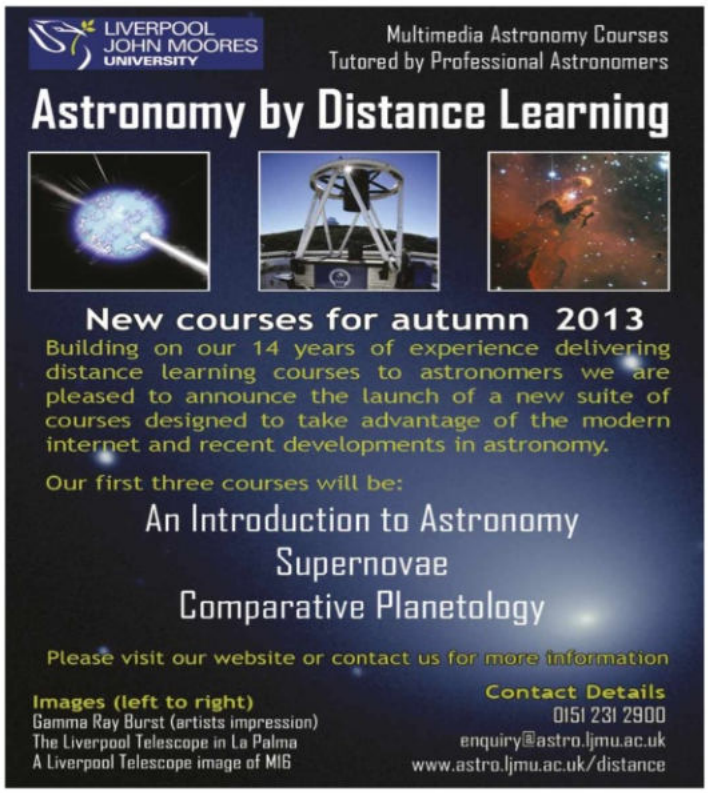
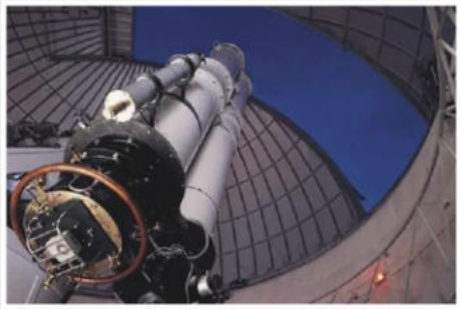


University College London



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MINDGAMES

BBC FOUR Pit your wits against these brainteasers by David J Bodycombe, question-setter for BBC Four's *Only Connect*

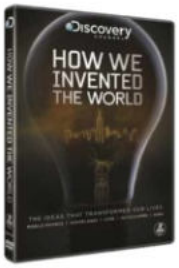
PRIZE PUZZLE

You have five blank cards. What letters should you write on each side of each card so that you could spell out any of the following words: RAKES, STOCK, EARLS, CLOSE, STARK, COLTS and ALTOS?

WIN! HOW WE INVENTED THE WORLD

The first five correct entries win a copy of *How We Invented The World* on DVD (Discovery Channel, Go Entertain).

Post your entry, marked 'Prize Puzzle 260', to: *BBC Focus Magazine*, PO Box 501, Leicester, LE94 0AA, to arrive by 5pm on 17 October 2013. We regret that we cannot accept email entries for this competition. See sciencefocus.com/winners for a list of previous winners and solutions.



See bottom of p104 for terms and conditions. Congratulations to Mike Harman (Swindon) and Blaine Malone (County Down) who answered the Summer issue's Prize Puzzle correctly to each win a copy of *Chasing Ice* on DVD.

Q1

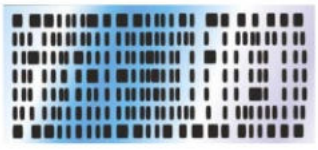
Which famous annual 'honour' by a US magazine happens to contain the 1st, 2nd and 3rd most common nouns in the English language, in that order?

Q2

What comes next: Boron, Carbon, Fluorine, Hydrogen, Iodine, Potassium...?

Q3

A scientist makes an unusual discovery on a microscope slide. What is it?

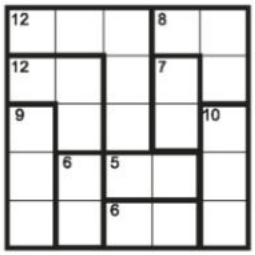


Q4

Find a pair of lines in this question that are the same length and perfectly parallel.

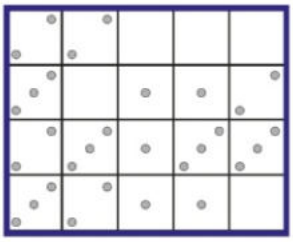
Q5

Write the numbers 1 to 5 in each row and column so that each 'section' contains the total indicated.



Q6

Divide up this rectangle into 10 essentially different dominoes (ie 2-3 is the same domino as 3-2).

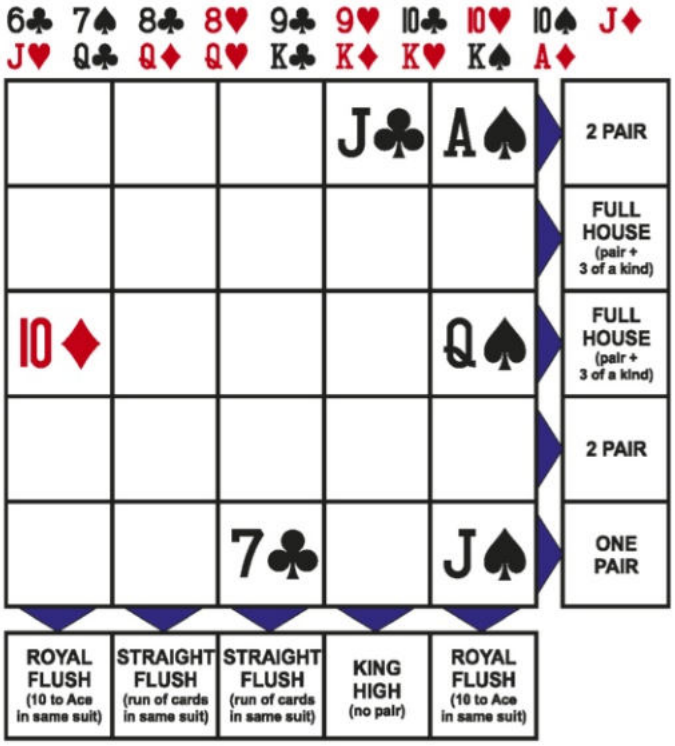


Q7

For each phrase, rearrange the letters into famous male/female pairings: JOKEY NAILS, NIAGARA BLEND, HEEL SPRAIN and RABBI KNEE.

Q8

Move the listed cards into the grid so that the best possible poker hand in each row and column matches the label shown. The cards are not necessarily in the right order (e.g. 5-4-6-7-3 still counts as a 7-high straight).



SOLUTIONS

Q1) Time 'Person of the Year' (Time, Person and Year being the most common nouns, according to the OUP).
Q2) Nitrogen. Elements whose chemical symbols consist of a single letter (in alphabetical order: B, C, F, H, I, K, N).
Q3) It looks like a coded DNA sequence, and in fact if you hold the diagram horizontal with your eyes, you can read the letters DEOXYRIBONUCLEIC ACID.
Q4) The two letter 'L's in the word 'parallel'.
Q5) Row by row: 12534, 54321, 43152, 25413, 31245.
Q6) There's a vertical Blank-2 in the top-right corner, and a vertical 2-3 in the bottom-left corner. All the other dominoes are horizontal.
Q7) KYLIE and JASON, BRAD and ANGELINA, PARIS and HELEN, BARBIE and KEN.
Q8) See illustration on p104.

QUICK QUIZ

How much do you know about Mars?

Q1

Mars's red colour comes from which chemical compound?

a) Aluminium oxide
b) Iron oxide
c) Silicon dioxide

Q2

What are the names of the two NASA rovers active on Mars?

a) Spirit and Opportunity
b) Opportunity and Curiosity
c) Curiosity and Spirit

Q3

Roughly how high is Mars's Olympus Mons volcano?

a) 5km
b) 15km
c) 25km

Q4

What's the most abundant gas in the Martian atmosphere?

a) Carbon dioxide
b) Nitrogen
c) Argon

Q5

When does the Inspiration Mars Foundation hope to launch a manned flyby mission to Mars?

a) January 2018
b) January 2028
c) January 2038

Q6

How long does it take Mars to complete one orbit around the Sun?

a) 287 Earth days
b) 487 Earth days
c) 687 Earth days

Q7

How many known moons does Mars have?

a) One
b) Two
c) Three

ANSWERS:

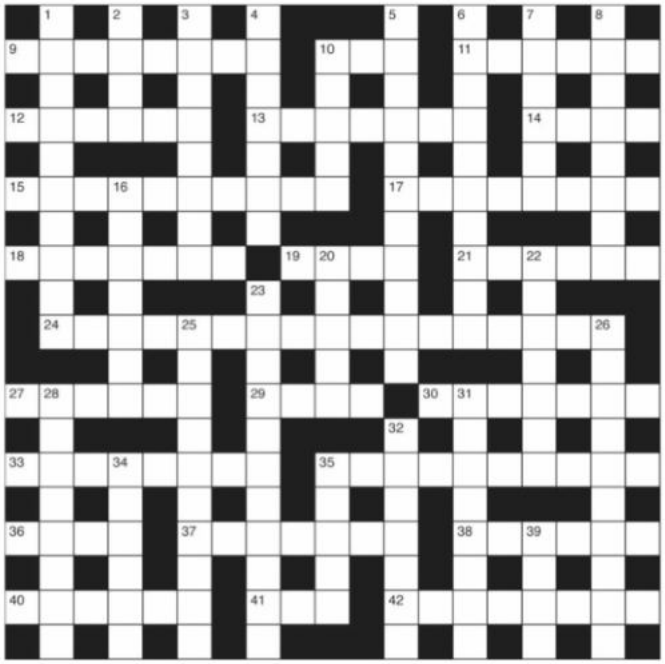
1b, 2b, 3c, 4a, 5a, 6c, 7b

YOU ARE:

0-3 An embarrassed rock
4-5 A blushing asteroid
6-7 A Red Planet

FOCUS CROSSWORD No 156

EVERY MONTH, A NEW CHALLENGE SET BY AGENT STARLING



ACROSS

9 Advance payment for a butler (8)
10 The field of pleasure (3)
11 Hard to find rowers of stature (6)
12 Principal design for plates (6)
13 Chart displayed alien wheel – with teeth (7)
14 Long tree (4)
15 Ideal to talk about hypothetical substance (7,3)
17 Protect and monopolise garden visitor (8)
18 Space to pay me off for collection of fluid (7)
19 Greet the weather (4)
21 Two articles registered part of a flower (6)
24 The same starting point, not like Lord's (5,7,5)
27 One bear roaming around one peninsula (6)
29 The affair of the bag (4)
30 Repeatedly spoil a sea (7)
33 A bit of pressure and I'm back getting sick at the pub (8)
35 Suggestive of a mood (10)
36 Bit of potato, or maybe silicon (4)
37 Smoke can infuriate (7)
38 Try air-conditioning, it's very unusual (6)
40 Using a drill can be dull (6)
41 Sailor finds viscous substance (3)
42 I have to follow after month is influential (8)

DOWN

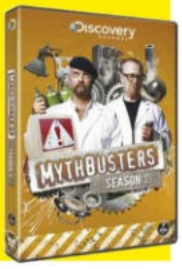
1 Gather mole was affected by heat from the ground (10)
2 Grouse or fish (4)
3 Crime not solved by local communication (8)
4 Group travelling round Indonesia catch disease (7)
5 Heathen plan involved ingredient of mothballs (11)
6 Princess joins friend in the sun (5,5)
7 As easy as a fraction (6)
8 His solution, mark you – a single tibia (8)
10 The position of a flower (5)
16 Insect finished at the bridge (7)
20 Answer arrives by ship in the Gulf (5)
22 Time to get recluse some welding gear (7)
23 Tie tricycle up and get juice (11)
25 Elf brigade constructed an opening connection (4,6)
26 Financial instrument is plagiaristic (10)
28 Trendy bishop started for the city (8)
31 A note to the office about precision (8)
32 A religious man has to finish a few supplements (7)
34 Fatty sauce only needs identification (6)
35 Victor misses top of target (5)
39 Impetuous complaint (4)

SOLUTION TO CROSSWORD No 153

Kathy Humphrey, R Gilmore, Shelia Smeal, Steven Barnett and Norman Faulkes solved issue 257's puzzle and each receive a copy of *Rise Of The Continents* on DVD.

WIN! *MYTHBUSTERS SEASON 2* ON DVD

The first five correct solutions drawn will each win a copy of *MythBusters Season 2* on DVD (Discovery, £15.41). Entries must be received by 5pm on 17 October 2013. See below for more details.



YOUR DETAILS

NAME

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Post entries to *BBC Focus Magazine*, October 2013 Crossword, PO Box 501, Leicester, LE94 0AA or email a scan of the completed crossword or a list of answers to october2013@focuscomps.co.uk by 5pm on 17 October 2013. Entrants must supply name, address and phone number. By entering, participants agree to be bound by the terms & conditions, printed in full on page 104. Immediate Media, publisher of *BBC Focus Magazine*, may contact you with details of our products and services or to undertake research. Please write 'Do Not Contact' on your email or postal entry if you do not want to receive such information by post or phone. Please write your email address on your postal entry if you would like to receive such information by email.

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INTO THE FUTURE

STEPHEN BAXTER

Your DNA could hold a message from an alien civilisation

THIS SUMMER IS a significant one for SETI, the Search for Extraterrestrial Intelligence. The 64th International Astronautical Congress will be held on 23–27 September in Beijing, China. This annual high-profile gathering of the major players in the space industry, including NASA and ESA, regularly includes a formal session on SETI. And in July a seminar at St Andrews University in Scotland launched the UK SETI Research Network (www.seti.ac.uk). This informal network of UK academics active in SETI – of which I'm one – was formed to promote new SETI activity in the UK. One possible example is Jodrell Bank making a search using e-MERLIN, a network of radio telescopes across the country.

SETI was launched in 1960 with the first attempts to detect signals from alien civilisations using radio telescopes (and the book and movie *Contact* showed how that might turn out, if successful). The fiftieth birthday of SETI has come and gone without a confirmed success. But what about other search methods? Even if we can't pick up aliens' messages, could we spot their ships? In 1996 space scientist Robert Zubrin calculated that an antimatter rocket, like the Venture Star of the movie *Avatar*, would have an exhaust so bright it could be directly detectable across many light-years. Even such advanced technologies as wormholes and warp drives could, in principle, be detectable from the radiation they produced.

Alternatively, what if we're looking for the wrong kind of signal? Recently much interest was created by a remarkable paper, published in May in the science journal *Icarus* by the Kazakh scientists Vladimir shCherbak and Maxim Makukov. It concerned a possible detection of a message artificially implanted in our DNA, which might have taken place far in the past, perhaps even when the DNA system first evolved.

"It's a possible detection of a message artificially implanted in our DNA, which might have taken place far in the past, even when the DNA system first evolved"

The double-helix structure of the DNA molecule encodes all the information required to build and control a living organism. It incorporates a coding system, analogous to a computer program. The code is stored in patterns of bases – A, G, C, T – but it could equally well be written down in mathematical symbols – and indeed has been transcribed into computer code for geneticists to analyse. The Kazakh scientists' suggestion is that the 'message' is stored not in any given DNA molecule, but in the mathematics of the coding system itself. An analogy might be a series of computer program lines, each beginning with a command such as:

If aliens have known about DNA all along, might they have altered our genes?

SET VALUE...
INPUT...
GO TO...
NULL VALUE ...

The program when run performs the functions that its programmer intended. But reading down the lines we see that the first letters give an additional message: SIGN. It's this additional message the authors claim to have detected.

It's a very stable messaging system. DNA will decay in a few million years at best, but the coding system itself has been preserved through the history of life on Earth, going back over three billion years. Perhaps such a 'message' could be a relic of meddling with the genetic system at the time of its formation. Whether the new claim holds up or not, it has certainly suggested new places to look for evidence of intelligence. I anticipate much debate about this in Beijing.

There is no sign yet of our giving up the search for ETI. After all, even a negative result would mean that at best intelligent life like ours is very rare. Or, perhaps, alien life is stranger than we have yet imagined. ■

STEPHEN BAXTER is a science fiction writer whose books include *The Science Of Avatar* and the *Northland* series

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